VARIOUS SCALES FOR COLOR–ESTIMATES

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The variety of symbols and scales now in use for expressing the colors of stars, and the desirability of reaching more uniformity, are too apparent to need any comment. This paper is intended to make a step forward in that direction. It begins with a historical review of the work done in this branch; then it defines the elements of color and their symbols; the scales of one and two dimensions and their co-ordination to each other, are then explained; and finally some proposals are submitted for the future.

The present exposition of the matter was occasioned by the re-observation of the star-colors contained in Sestini's Catalogue, with a view of republishing the latter in more convenient form. The volume will appear in the course of next year, as No. 3 of the new series, "Specola Vaticana," and will contain a more exhaustive treatise on the scales of color-estimates. It may be agreeable to many readers to have its substance presented in English. By referring to the forthcoming Italian publication, we have the advantage of not incumbering the present article with too many references to the sources, and of saving a graphical representation, which will be found there.

I. HISTORICAL SKETCH

Colors of stars are mentioned in four different groups of astronomical literature. of which only one will concern us here. There are the *double stars*, the colors of which were first observed by the

two Herschels (1782 and 1847), then by Dunér (1876), O. Struve (1878), and others.   Most of O. Struve's and Dembowski's estimates are found in Burnham's *General Catalogue*.   All these observations were made occasionally, without the purpose of establishing any systematic method or nomenclature.   Then there are the *red stars*, so called, as distinguished from the great mass of yellow stars by their deeper orange or reddish hue.   It is well known that four of our most conspicuous reddish fixed stars are mentioned in the Almagest, as standing out from the yellowish tint of the rest. Lalande gave (1807) a list of 33 "red stars."   The first who made a critical collection of all that was known about red stars, was Schjellerup (in 1866 and 1874).   Then followed a catalogue by Schmidt (1873), the *Prodromo* of Secchi (1876), and observations and catalogues by Birmingham (1877), by Lindemann (1879 and 1882), and by F. Krüger (1893).   Comprehensive bibliographies have been published by Knobel, Espin, and Krüger.

Colors of *variable stars* are first mentioned in connection with the *Nova* of 1572, by Tycho Brahe.   Argelander did not observe them much himself; but proposed the first scale in 1844, which was used for thirty-six years by his disciple Schmidt.   Colors of variable stars were observed a great deal by the English astronomers Pogson, Baxendell, and Hind.   Lists of those colors are found in the "Notes" to the catalogues of Pogson (1856) and of Schönfeld (1866, 1875).   Special columns for the color were first used by Gore (1887) and Chandler (1888, 1893, 1896).   In the Harvard catalogues of variable stars the spectral type is given instead of the color, but Table V of the Second Catalogue contains a column for the color.

The three groups of literature hitherto mentioned treat of colored stars, not of *star-colors* in general.   Of the latter we now possess four published catalogues: the first by Sestini (1845 and 1847), which contains all the stars of Baily's Catalogue, down to $-30°$ declination; then Vol. XIV of the *Harvard Annals* (1884), with a column of observations by Franks; further the *Photometric Durchmusterung* of the northern sky, by Müller and Kempf (1894–1907), and finally Osthoff's Catalogue (1900) of all the bright stars within the first five magnitudes, down to $-10°$ declination.

What follows deals only with direct estimates of color by the eye and, consequently, excludes all kinds of *colorimeters*, such as were either described or used by Secchi (1852–1856), by Kincaid (1867), by Zöllner (1868), by Christie (1874), by Lindemann (1882), and by Chandler (1888), and also the *photographic* method, which is being experimentally studied by Schwarzschild, Parkhurst, Bergstrand, and others.

II. THE ELEMENTS OF COLOR AND THEIR SYMBOLS

1. While in the physical theory of colors three *elements* have to be distinguished, brightness, tone, and shade, in practical astronomy the brightness of the stars has been considered separately from color, and is known under the name of magnitude.   The other two elements, tone and shade, cannot be separated in a theory of color, be it the chemical theory of pigments or the physiological theory of color-perception, the physical theory of the spectrum, or finally, the astronomical theory of star-colors.

Much ambiguity, however, prevails as to nomenclature.   The terms tone, hue, shade, and tint are given as synonyms in most dictionaries.   To remove all ambiguity from this article, tone and shade are here used in their technical meaning as the *qualitative* and the *quantitative* elements, respectively.   The quality of color depends on its position in the spectrum and the quantity on its mixture with the two auxiliary colors: white and black.   The technical designation of the two elements should conform to their definitions.   The colors of the spectrum are often compared to the gamut in music, and to this analogy it is due that Newton, in his *Optics*, distinguished seven colors of the spectrum.   If then the spectrum is a chromatic gamut, its colors are the tones.   In like manner, if the quantity of color depends on its mixture with white or black, it may properly be called shade or *nuance*, which latter word is derived from *nubes*, "cloud."   French writers, like Chevreul and Lacouture, use the expressions *ton* and *nuance* in exactly the reversed sense.   Maxwell restricted the term "shade" to admixtures of black, and called the paler shadings "tints."   We shall avoid the double term, for fear that the reader might consider

tone, shade, and tint as three essentially different elements of color, while in reality the latter two mean only more or less shading.

In measuring colors, both elements—the qualitative and the quantitative—must be referred to certain *scales*. The scale for the quality of color consists in the selection of *fundamental* or simple colors to which all the others can be referred. The selection will be a different one for different theories of color. In the art of painting, red, yellow, and blue are usually considered the primary colors. Leonardo da Vinci added green as a fourth one; but this has been declared a mixed color by Waller (1686), Chevreul (1851), and all following writers. It has been mentioned that Newton established seven principal colors in the physical theory. Later on, his distinction between blue and indigo was dropped. In physiological optics, Young chose red, green, and violet as the primary sensations; in all probability, because red and violet form the extremes and green the middle of the solar spectrum. From experiments on color-blindness, however, Helmholtz and Maxwell were led to replace violet by blue. Sir William Abney returned to violet and modified the places of the primaries in the spectrum.

The astronomical theory of star-colors cannot accept its scale of tones from either chemistry or physics or physiology; it has to take the fundamental colors from what the stars actually show, after their light has passed through our atmosphere. This maxim was followed by Argelander in 1844, as we shall see in the next section.

The quantitative element of color must likewise have its scale or gradations. Newton represented it graphically, by arranging the colors of the spectrum along the circumference of a circle, whose center represents white. The quantity, or saturation as he called it, of any color within the circle is then proportional to the length of its radius, i.e., to its distance from white. Newton considered likewise the mixture with black as a quantitative element of color, but did not comprise it in his geometrical design. We shall return to this point presently. It follows from Newton's way of representing the two elements of color, that the solar spectrum was to him the normal, and at the same time the maximum, saturation.

From this normal quantity all the colors diminish in two directions: toward white and toward black. The *paler* colors (Maxwell's tints) are also called undersaturated, while the *darker* shades are oversaturated. They form the scale for the quantity of color.

Returning to Newton's chromatic circle we hope to show that it leads naturally to a chromatic sphere, with the spectral colors along the equator and the auxiliary colors, white and black, as its poles. Newton gave a diagram of the colors in Fig. 11 of Tabula III of his *Optics*. The seven chromatic sectors are not all of the same width (he makes them proportional to the seven intervals of the gamut), and are not homogeneous either in radial or in angular direction. The center represents white and the line separating two sectors represents the mixture of the two. The middle color of any sector is modified toward either of its two limiting radii by adjectives. Thus the yellow sector has the two modifications orange-yellow and greenish-yellow. Newton's Latin expressions *flavus aurescens* and *flavus viridescens* show that in Latin, as in all its derived languages, the modification stands on the right of the principal color, while in all the Germanic languages the order is reversed. This has to be remembered, when O. Struve's Latin color designations are rendered into English. Newton found by experiment that the colors which lie in opposite directions on the circle, or on the same diameter, when mixed in proper proportions, produce gray but never white. The designation "complementary" for such colors was probably introduced by Chevreul in 1839.

The want of the other pole for black, in Newton's diagram, was pointed out by Lambert (1772). Curiously enough he supplied it by the vertex of a cone erected over the circle as a base. In the successive parallel sections the pole white gradually changes into black. It is hard to see why Lambert preferred the cone to the sphere. The latter is, to the writer's knowledge, not mentioned in the literature on the subject. Only Chevreul speaks of a "construction chromatique-hémisphérique;" yet all his diagrams seem to represent a plane. On the chromatic sphere, with the two poles white and black, and the spectral colors along the equator, any two half-meridians include a constant tone, and any two parallel circles a constant shade. Each diameter designates two comple-

mentary colors, giving gray together. Hence white and black are likewise complementary.

Where only three primary colors occur, as in the theory of color-sensation, the triangle has offered itself as a simple diagram. The primaries are assigned to the three angles, and white is placed in the center of gravity. The diagram might be extended to represent the dark colors as well. It is only necessary to replace the triangle by a tetrahedron, with white at the fourth angle. A second tetrahedron would have black in the place of white, and both would be brought base to base so as to make the primaries coincident.

2. On the chromatic sphere the scales of the two elements of color are at once apparent. The scale of the tones consists in the meridians, and the scale of the shades in the parallel circles. The next question is to find proper *symbols* for them. Four kinds of symbols have been in use: (*a*) technical words; (*b*) colored diagrams; (*c*) numbers, and (*d*) letters.

a) *Words* have been used to define the tones of colors by designating Fraunhofer's lines in the spectrum, or by naming natural objects of corresponding coloration. Much less definite are the words used for designating tint and darkness of colors.

b) A first but very imperfect *diagram* of chromatic tones and their shadings was published by Waller, in 1686. Much more artistic representations of colors were given by Chevreul (1839) for industrial purposes. Those of his follower, Lacouture, are unsurpassed in beauty and correctness. Colored diagrams, especially designed for star-colors, are found in Smyth's *Sidereal Chromatics* (1864); they give six different tones, each with four degrees of shading, or twenty-four pictures in all. The many representations of the solar spectrum are intended for tones only, while the shading necessarily inherent in them may serve as a measure of their artistic perfection.

c) *Numbers*, as steps in the chromatic scale, were first used by Klein (1868), with the explicit purpose of imitating Argelander's magnitude-scale. Dealing only with strongly colored stars, he divided the interval yellow to deep, fiery red into five steps, from o to 5. Schmidt extended the scale to all the stars, and, keeping

practically Klein's steps, moved the numbers backward toward white and ended with 10 = red. This was in 1872. Safarik (1879) speaks in one place of twenty grades that he used. Köhl (1878) had a scale of eleven steps, from 1 = deep red to 12 = white. Innes (1898) passes from 1 = red, over 8 = white, to 14 = reddish violet.

Even less uniformity prevails in the numerical designation of shades. Chevreul counted ten grades of saturation on either side of the normal one, or twenty from white to black. The ten grades of Chevreul were afterward (1890) reduced to six, on either side of the spectral colors, by Lacouture. In *Sidereal Chromatics* Smyth chose four grades from deep saturation toward white, and put the numbers in the form of exponents over the diagrams as well as over the words designating the quality of color. The same notation was followed by Espin (1886), Franks (1887), and Backhouse (1905)—the latter two, however, in the opposite direction from Smyth, calling 1 = white-tinged and 4 = deepest tint. Krüger counts 1, 2, 3, in the same direction with Franks.

d) Letters came into use as symbols of the quality of colors in the years 1883–1887. Naturally they were always the initials of the corresponding words. It will be noticed that the English language is the only one that furnishes these initials without ambiguity. The priority of letter symbols is due to H. W. Vogel (1883). He started from the three primary or simple colors:

$$W, \quad G, \quad R,$$

and, by means of combinations and permutations of the symbols, interpolated four mixed colors between them; thus:

$$W, \quad GW, \quad WG, \quad G, \quad RG, \quad GR, \quad R.$$

Following Argelander, he considered white as one of the principal sidereal colors; he made a mistake, however, by omitting one of Argelander's colors between white and red. Whether his G mean yellow or orange, one of the intervals W–G or G–R is necessarily too large. Vogel gave no symbols for the quantitative element.

The next year the "Harvard Photometry" appeared (*H.A.*, **14**, 1884). On p. 94 the letter symbols are defined as the initials of the English names of all the colors used by Mr. Franks. They are the six principal colors of the spectrum:

$$R, \quad O, \quad Y, \quad G, \quad B, \quad P,$$

with the additional colors W = white, and L = lilac. Combinations of letters are avoided, but the shading of the colors is expressed in three grades, by capital Latin, small Latin, and small Italian types, in the order from strong to faint saturation.

A combination of the symbols R and O was used the first time by Espin (1886).

Mr. Franks proposed afterward (1887) to keep the six principal types mentioned above, with a few modifications. White should be designated by O, as in Newton's chromatic circle; this necessitated expressing orange by Or. The letter P was afterward changed into V. The shades were to be indicated by numerical exponents, following Smyth. Krüger, in his Catalogue of 1893, held to Vogel's symbols, but improved them by putting O between G and R.

In Lacouture's *Répertoire chromatique* (1890), we meet the French initials, and for the first time also a special symbol for black. White and black are used to indicate the shadings. Mixed pale or dark colors were thus expressed by three letter symbols.

We said before, that the English initials (as first used by Professor E. C. Pickering) are the only ones that admit of no ambiguity. If the auxiliary color black is introduced, the initial B cannot be used. Here the letter S would recommend itself, as the initial of "somber" (= *sub-umbra*). It would also accord with the French *sombre*, the German *schwarz*, and the Italian *scuro*.

III.   COMPARISON OF THE VARIOUS SCALES

There have been two scales in use in sidereal chromatics, which may be called the *linear* and the *areal* scales. The symbols of the former are mainly numerical, those of the latter literal. Once the two sets of symbols are correlated to one another by some rule, the comparison between the two chromatic scales will be obvious.

1. The *areal*, or two-dimensional, scale has its origin in Newton's chromatic circle, and has been developed by English astronomers. Smyth, Franks, and Backhouse agree in the choice of six *fundamental* colors:

red, orange, yellow, green, blue, violet (or purple),

and of four degrees of chromatic intensity; but the arrangement of tones and shades is different in the case of Smyth from that of the other two. First, the diagram of Smyth is rectangular, that of Franks and Backhouse circular: the former using parallel co-ordinates, as it were, the latter polar co-ordinates. The normally saturated colors are also marked differently: they have the index 1 in the rectangle, and the index 4 on the circumference of the circle.

The symbols of the six fundamental colors lend themselves at once to the designation of mixed colors by combinations of any two of them, and, if desired, by permutations, putting the symbol of the modifying color to the left of the predominant one.

A peculiarity of the two-dimensional chromatic scale, although not a necessary one, consists in not using white and black as auxiliary colors. We shall presently see that white was proposed by Argelander as one of the fundamental colors, and we remember that it was adopted by Vogel in 1883. In the arts of painting and dyeing black is considered as a color, and in physiological optics a special sensation is attributed to it by Helmholtz. A symbol (N) was assigned to black by Lacouture, and the combination of this symbol with those of the spectral colors gave the shadings of the darker colors. For variable stars, in particular, the darker shadings should be contained in the scale; and hence the chromatic sphere would seem to be a better system of two co-ordinates than the circle. Besides this, we hope to show in the last section that the two symbols W and S will express all the grades of shading that an observer can estimate directly.

The *linear* or one-dimensional scale owes its origin to Argelander. In his "*Aufforderung*" of 1844 he proposed the chromatic scale:

<div align="center">purpur, rot, orange, gelb, weiss, bläulich,</div>

"with two or three gradations between them." Here we find white, where the solar spectrum places green. The scale seems to represent what Argelander actually saw in the stars, independently of any chromatic theory. It is quite likely that by *purpur* Argelander meant to express what he observed in the variable stars when they decline toward their minimum brightness, i.e., a darker shade of red. In like manner his *bläulich* is not a fundamental color;

it means the faintly bluish tint in which white stars sometimes appear.

Argelander's scale was used by Schmidt for nearly forty years. Schmidt divided the interval between white and red into ten grades and fixed the four fundamental colors on the following numbers:

white=0, yellow=4, orange=6, red=10.

We hope to show that the numbers 0, 4, 6, 10, which follow no law, could advantageously be replaced by the arithmetical progression: 0, 3, 6, 9. These numbers would respond better to the "two or three gradations" that Argelander proposed between the fundamental colors.

The four primary colors of Argelander have almost universally been adopted in Europe and America. They were used by Secchi in his *Prodromo* (1875), without a proper scale; by Safarik, with ten or twenty divisions; by Chandler and Yendell, with nominally ten, but in reality only six grades; by Krüger (1893) and Osthoff (1900), who both followed Schmidt's gradations.

Independent of Argelander's proposition are the observations of Sestini, whose *Primo Tentativo* (1843) antedates the *Aufforderung;* then those of Lindemann, who describes the colors like Sestini; and finally those of Vogel, in so far as he omitted one of the two colors between W and R, and reduced Schmidt's scale from ten to six grades, in order, as he said, not to have "too many subdivisions." In the course of the Potsdam *Durchmusterung* it was found, however, that the subdivisions were insufficient, the chromatic steps being on the average almost twice as large as those of Schmidt. The remedy which was applied is well known: by means of the suffixes ± each of the six intervals was divided into three, which gave a scale of eighteen grades between W and R, with an average value of nearly two-thirds of Schmidt's chromatic grade.

2. If now some mathematical *correlation* could be established between the literal and the numerical symbols, the result would be, not only a comparison between the scales of one and two dimensions, but even an easy transition from one to the other without ambiguity. Fortunately this correlation can be made simply by changing the

four irregularly distributed numerals of Schmidt: 0, 4, 6, 10, into the arithmetical progression:

$$0=W, \quad 3=Y, \quad 6=O, \quad 9=R.$$

Between these four cardinal points the combinations and permutations of the four letters will exactly fill the numerical intervals, as shown in the following table:

TABLE I

WHITE			YELLOW			ORANGE			RED		
BW	**W**	YW	WY	**Y**	OY	YO	**O**	RO	OR	**R**	SR
−1	**0**	1	2	**3**	4	5	**6**	7	8	**9**	10

The two limiting shades −1 and 10 are supposed to correspond to Argelander's limits, *bläulich*=bluish-white and *purpur*= somber-red. The scale may be called the *chromatic scale of nine grades*, not as if it were limited to so many grades, but because it divides the interval R to W into nine steps; just as the Centigrade thermometer has its name, not from the actual number of degrees, but from its division between boiling and freezing points. The difference between this scale and that of Schmidt consists mainly in that it puts the yellow one grade nearer to white. The difference in the red will hardly ever be noticed on account of the scarcity of stars which deserve the symbol R. In Vogel's scale one of the two middle sections of Table I is cut out. Chandler has put orange on 4; consequently his large grades would reach red with the number 6. While Krüger and Osthoff adhered strictly to Schmidt's scale, that of Safarik agrees better with ours; for he has:

$$3=\text{straw-yellow}, \quad 6=\text{orange}, \quad 9=\text{blood-red}.$$

Klein's numbers are exactly five units smaller than in our scale, his 0, 1, 2, 3, 4, 5 being identical in definition with our 5, 6, 7, 8, 9, 10.

The advantage of the nine-grade scale consists in its symmetrical construction. The observer has only to remember the principal grades 3, 6, 9—all multiples of 3. Practically he has to impress on his mind only the two standard colors corresponding to 3 and 6.

Once he has fixed the two cardinal points, he will add to each one grade forward and one backward, to acquire the two middle sections of Table I. Adding the same two modifications to the limiting colors W and R, he will be in possession of the entire scale from −1 to 10.

3. After having slightly modified the linear scale, we suggest a similar change in the scale of two dimensions. It will consist in reducing the four degrees of saturation to three, in order to co-ordinate them to the three shadings:

YW, WY, Y.

For this purpose we construct on the chromatic sphere, between pole and equator, two parallel circles representing these degrees of saturation. It is now an easy matter to trace the linear scale upon the sphere. It will be a line broken in the three points: W, Y, R. We begin by putting the number 0 on the pole W. The numbers 1, 2, 3 will then run along the meridian marked Y, cutting the two parallels in 1 and 2. Number 3 will lie on the equator; and along that fundamental circle the linear scale will run as far as R = 9. From this point it will pass along the meridian marked R to the other hemisphere as far as the first parallel, where we place number 10. There remains number −1, which we reach by producing the scale backward from the pole W on the meridian B as far as the first parallel. A large diagram, printed in two colors, and representing the linear scale within the scale of two dimensions, will be found in the forthcoming volume of the Vatican Observatory.

The combination of the two scales in one diagram shows that the linear scale is not exclusively one of tones or one of shades, but a mixture of both. Its *raison d'être* has been illustrated by comparing the colors actually seen in the stars to those which a solid mass apparently passes through, when cooling off from white incandescence to a deep red (see *American Journal of Science*, **19**, 467, 1880). We say "apparently," for although blue and green are not perceived in the cooling process, the presence of these rays can hardly be doubted. It seems as if the rays of shortest wave-length were the first to disappear in the process and those of largest wave-length the last, as in fact the heat rays remain after all the visible rays have

vanished. When the blue rays in a white star have disappeared, the green in combination with the red will produce the sensation of yellow. It would seem, therefore, that the linear scale corresponds to what is actually seen in the stars, at least in a general way. It remains true, however, that sometimes the scale exercises coercion on the observer.

Combinations of colors like BY, RY, and even RW, which do not contain the intervening tones of the linear scale, are observed, as is testified by Sestini, Franks, Krüger, and by the writer, although other observers seem to doubt it. As there are no numbers provided for the combinations mentioned, the observer will, in all such cases, have to pass from the numeral symbols to letters.

A great difference seems to prevail between the two scales with regard to taking the mean of a number of observations. Arithmetically the operation is obvious in the linear scale, although it would lose its physical meaning, if the estimated numbers differed more than two or three units. In the circular or spherical chromatic scale the method of taking the mean has never been explained. Vector analysis suggests a method. In that scale, colors are designated by vectors (straight or spherical). The half-sum of two vectors is a third vector drawn to the middle point of the line which joins their extremities. Incidentally this operation shows that the degree of saturation would be better designated in the form of coefficients than of exponents. Thus, the symbolical operation:

$$\frac{1}{2}(y^1 + y^2) = y^{\frac{3}{2}}$$

would look better mathematically if written:

$$\frac{1}{2}(1y + 2y) = \frac{3}{2}y .$$

IV. SUGGESTIONS

Should there ever be question of introducing more uniformity in the notation of sidereal colors, the following suggestions may serve as a preparation:

1. The foundation for further deliberation seems to consist in the following points:

a) The two scales of one and two dimensions may be allowed to exist together. The latter has proved itself useful mainly in the observati on of double stars, while the former is more applicable t single stars and especially to variables.

b) Accordingly both numerical and literal symbols may be used, the latter being the initials of the English denominations, with the auxiliary S = somber.

c) The two scales should be correlated by a mathematical rule, so as to make the transition from the one to the other easy and without ambiguity. In this way they will supply the defects of each other, and may be considered as two modifications of one general scale.

d) The correlation can be effected by reducing the ten grades of Schmidt to *nine*, and the four shadings of Franks to *three*.

Table I (page 271) will present the solution of the problem.

2. A secondary question is the notation of the shading of colors. The following points are proposed:

a) In every chromatic scale it must be possible to express the degree of saturation. This, however, seems to be needed only in the fundamental or simple colors, because there alone it is clearly perceptible. In mixed colors a distinction must be made between the relative saturation of the components and the absolute saturation of the compound. The relative shading will appear to the observer as the predominance of one component over the other, an impression which he will denote by the permutation of the literal symbols or by the correlated numerals. Thus, if in a mixture of O and R, the latter has a deeper shade than the former, he will denote it by OR = 8; if on the contrary O is more saturated than R, he will write RO = 7. If the compound of O and R shows a tendency towards W, it will, first of all, appear as RO = 7 and not as OR = 8. The contrary will take place when the tendency is towards a darker shade. The question then turns about a pale RO and a dark OR. Now experience seems to show that it is very difficult to distinguish between a pale RO = 7, and O = 6; or between a dark OR = 8, and R = 9. Experience seems likewise to show that the errors of observation are larger than the differences indicated. In the *Memoirs of the British Astronomical Association* a very pale

orange-yellow is denoted thus: OrY^1, which stands for $(OrY)^1$, and is the nearest tint to white. It seems to be questionable whether, in that very pale mixture, the component orange can be perceived beside the yellow. The difficulty of perception is not so great in the simple colors: a pale R can be distinguished from OR, and a pale O from YO. Likewise there is a difference between a dark O and RO, and between a dark R and violet red.

The advantage of restricting the notation of shade to the fundamental colors lies in the fact that any tone or shade of these colors can be expressed by two symbols at the most, while shades of mixed colors require three symbols.

b) Once the notation of chromatic shades is limited to three degrees on either side of normal saturation, and to the fundamental colors only, there is the choice between two sets of symbols:

The numerals 1, 2, 3, 4, 5 express the shades from very pale to very dark. On the chromatic sphere the two poles are $W=0$, $S=6$, and the index 3 belongs to the equator. In the British Astronomical Association the numerals are used in the form of exponents over the letters. Another set of symbols was used in Table I of the preceding section, viz., the two letters W and S. It will be remembered that the numerals -1, 1, 2, and 10 in the linear scale of nine grades express shades. They are here repeated, with the two sets of symbolical notation:

TABLE II

Areal scale	B^1	Y^1,	Y^2	R^4
Linear scale	-1	1,	2	10
Correlation	BW	YW,	WY	SR

c) The suggestion we wish to make is contained in Table II. The letters W and S, combined with any letter symbol of the fundamental colors, will express a pale or dark shading of that color, and the permutation of the combined letters will express two degrees of each shading, beside the normal saturation (without W and S). On the chromatic sphere the permutations with W or S represent the two parallels between equator and pole.

The application of the suggestion to the areal scale would be to replace the exponents by the letters W and S. The application to the linear scale would mean to employ letter symbols beside the numerals, wherever needed, and to consider the correlation established between them in Table I as a bridge for easy transition from one system to the other.

3. The suggestions made in paragraphs 1 and 2 would yield the following advantages:

a) In the two-dimensional scale all the tones and shades would be expressed by two symbols at the most. The letter symbols would be understood without a key, at least in the Germanic languages.

b) The linear scale would supplement its own deficiencies through the correlation between letters and numerals, for instance in the following combinations, WR, WO, SO, BY, etc., which are not expressible in the numerical scale.

c) The same correlation would make the reading of observations easy for all, no matter what scale they used themselves. And all that has to be remembered is: $Y = 3$, $O = 6$, $R = 9$.

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THE ABSORPTION SPECTRUM OF SELENIUM VAPOR, AND THE EFFECT OF TEMPERATURE UPON IT

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The first investigation of the absorption spectrum of selenium vapor was carried out by D. Gernez,[1] who found that below 700° C. the vapor gave complete absorption except in the red. Above 700° C. absorption bands, which correspond with bands in the emission spectrum, appeared. Lockyer and Roberts[2] found that the vapor gave a fluted absorption spectrum. Since selenium is one of those substances giving anomalous values for the vapor-density, it is interesting to determine the changes produced in the absorption spectrum by rise of temperature. At 860° C. the vapor-density is 110.7, and at 1420° C. the vapor-density is 81.5, which nearly corresponds to the normal density of the diatomic molecule Se_2 (78.5). Selenium vapor at comparatively low temperatures consists of a mixture of diatomic molecules and aggregates of greater molecular complexity, but at temperatures above 1500° C. the vapor consists almost wholly of diatomic molecules. Graham,[3] as the result of his investigation of the absorption spectrum of sulphur vapor between 500° C. and 900° C., was able to determine the spectra belonging to the S_2 and S_8 molecules respectively. The diatomic molecule S_2 gives bands between λ 2600 and λ 3415, while the more complex molecule S_8 gives bands between λ 3985 and λ 4775.

In the case of selenium the experimental difficulties are great, because of the high temperature at which the normal vapor-density is obtained and besides, as far as the present authors are aware, there is no definite knowledge of the nature of the molecular complexes present at comparatively low temperatures. In the present work the absorption spectra of selenium vapor at high and low temperatures (vapor-pressure constant) will be described. Experi-

[1] Comptes Rendus, **74**, 803, 1190, 1872.

[2] Proc. Roy. Soc., **23**, 344, 1875.

[3] Ibid., A, **84**, 311–324, 1910.

ments were also carried out with a known weight of selenium placed in a quartz tube, and the absorption spectrum photographed at different temperatures. The effect of temperature on the absorption spectrum was carefully noted, and in certain cases the wave-lengths of the absorption bands were measured. The values obtained are, however, only approximate, being correct to a few Ångström units.

EXPERIMENTAL ARRANGEMENT

It is unnecessary to give a full description of the experimental arrangement as it is similar to the one previously employed in an investigation of the effect of high temperature on the absorption spectrum of iodine.[1] The selenium was introduced into a quartz tube, which was provided with transparent quartz ends, and also a side-tube of small diameter. When the absorption of a constant mass of vapor was studied, the side-tube was short, but when the absorption at constant pressure was studied, this side-tube was several inches long. The quartz tubes (each about 10 cm long and having a capacity of about 30 cc) were dried, and after the selenium was introduced, evacuated to a pressure of a fraction of a millimeter. Dry hydrogen was now allowed to enter the tube, which was again evacuated. The process of filling with hydrogen, and evacuating was again repeated, and when the pressure was only a fraction of a millimeter, the side-tube was sealed off in the oxyhydrogen flame. The quartz tube was placed inside an electric furnace, one wound with an alloy of nickel and chromium for temperatures up to 1200° C., and a carbon-tube furnace for higher temperatures. The temperature was read off in degrees Centigrade on the scale of a galvanometer, to which a *Pt—Pt-Rh* thermo-couple was connected. When a constant vapor-pressure was required, the following arrangement was adopted. The side-tube protruding from the end of the furnace was placed inside a larger tube also made of quartz. This tube was wound with nickel wire, and the windings were continued on the side-tube to within a few centimeters of the clear quartz ends of the tube inside the furnace. The pressure of the selenium vapor in the quartz tube is the vapor-

[1] *Astrophysical Journal*, **32**, 1, 1910.

pressure corresponding to the coldest part of the apparatus. In the present work the end of the side-tube was made the coldest part of the apparatus, and the temperature was recorded by placing a thermo-couple inside the larger tube, and pushing it just over the end of the side-tube. Unfortunately no data giving the vapor-pressures of selenium at different temperatures could be obtained. The positive crater of the electric arc was employed as a source of light, and two lenses (quartz lenses for ultra-violet) were used to bring the spot of light to a focus on the slit of a concave grating of 1 meter radius and 1500 lines to the inch. Since selenium absorbs strongly in the blue, violet, and ultra-violet, its absorption spectrum was studied photographically by means of Wratten and Wainwright's "panchromatic" plates. The first-order spectrum was employed throughout the present research.

DIFFICULTIES

Selenium heated in air or oxygen forms on cooling a white oxide (SeO_2), which crystallizes in long needles. This oxide rapidly evaporates at about 300° C., forming a greenish yellow vapor whose absorption spectrum has been investigated by Gernez.[1] It gives a channeled absorption spectrum in the blue and violet. It was therefore necessary in all experiments on the absorption of selenium vapor to heat the selenium in a vacuum, or in an atmosphere of carbon dioxide. The method actually adopted has been described above, and when the quartz tube was ready for use, it only contained very small traces of air and hydrogen. The photographs did not show the characteristic bands of SeO_2 in the blue and violet. Two of the quartz tubes were found to leak at temperatures of 900° C. and 1000° C., and this was evident from the color of the light falling on the slit of the grating spectroscope. When the tube was taken out of the furnace, the surface of the quartz was found to be covered with the white, needle-shaped crystals of the dioxide. In other cases the selenium showed no signs of having been converted into the dioxide, and the vacuum was good after prolonged heating to 1000° C.

[1] *Comptes Rendus*, **74**, 1190, 1872.

EXPERIMENTAL RESULTS

Since selenium dioxide may be formed during the course of experiments on the absorption spectrum of selenium vapor, it was considered advisable to make a brief examination of the absorption bands due to the former. Some of the oxide was prepared by heating selenium in a current of oxygen, and about 0.006 grams of the white, needle-shaped crystals were placed in a tube of Jena glass, which was afterward evacuated and sealed. The tube was then introduced into the electric furnace, and the absorption spectrum of the vapor examined at a temperature of about $350°$ C. The approximate wave-lengths of the SeO_2 bands from the violet to the blue are as follows: 3930, 3960, 3990, 4020, 4055, 4083, 4117, 4157, 4185, 4220, 4256, 4290, 4330, 4365, 4395, 4437, 4470.

The breadth of the bands varies from about 15 to 40 Å., and the 4437 and 4470 bands are double (4437 and 4470 are the approximate mean wave-lengths of the double lines). The photographs do not show the presence of any bands between 3800 and 3600.

About 0.006 grams of SeO_2 were again weighed out, and introduced into a quartz tube, which was evacuated to about 1 cm pressure, and the side-tube sealed off in the oxyhydrogen flame. The absorption spectrum was photographed at $360°$ C., $600°$ C., and also at $900°$ C. The low-temperature photograph shows the presence of bands in the blue and violet, and in addition bands in the ultra-violet between λ 3800 and λ 3200. The photograph taken at $600°$ C. only extends from λ 7200 to about λ 4200, and shows a few bands due to SeO_2, and traces of bands due to selenium vapor. Beyond λ 4200 in the violet and ultra-violet there is complete absorption. The third photograph also indicates complete absorption beyond λ 4200, and an examination of the absorption bands in the blue shows distinctly the presence of selenium. The ultra-violet bands between λ 3200 and λ 3800 are considered to be due to the vapor of metallic selenium and not to the dioxide. The SeO_2 crystals employed in the above experiments were not absolutely white, and at the time it was considered probable that the crystals were mixed with small traces of selenium. This explanation of the origin of the ultra-violet bands was also borne out by subsequent experi-

ments on the absorption spectrum of selenium vapor, when care was taken to exclude the presence of oxygen.

THE ABSORPTION SPECTRUM OF SELENIUM VAPOR

When the pressure of the selenium vapor in the quartz tube is comparatively large, the color of the image on the slit is deep red, and the spectrum of the light passing through the vapor extends from λ 7200 to λ 5800.   There is continuous absorption below λ 5800, and also no absorption bands are observed in the region 7200 to about 5800.   As the vapor-pressure is diminished (temperature of the vapor being kept at 600° C.) absorption bands are observed in the green, blue, and violet, and when the vapor-pressure reaches a low value, bands are observed in the ultra-violet.   The ultra-violet bands make their appearance when the temperature of the solid selenium in the coldest part of the side-tube is about 40° above the melting point (217° C.) of the metal.   The experiments indicate that the absorption by the vapor increases continuously from the extreme red to about λ 2400 in the ultra-violet. The absorption by thin films of the solid was investigated by R. W. Wood,[6] who found that it increased continuously with diminishing wave-length until λ 2200 was reached.   In the ultra-violet absorption spectrum of the vapor no bands were detected of shorter wave-length than 3200 (i.e., between λ 3200 and λ 2300).

EXPERIMENTS WITH CONSTANT MASS OF VAPOR IN TUBE

Series I

In the first series of experiments about 0.005 grams of selenium were introduced into a quartz tube (10 cm long, volume about 20 cc), which was evacuated to a pressure of 0.5 cm of mercury before sealing off in the oxyhydrogen flame.   The tube was then heated in a carbon-tube furnace, and the absorption spectrum was observed visually at various temperatures from 350° to 900° C. At 450° the spot of light falling on the slit of the grating was yellow in color, becoming deep red at 600°.   In the latter case only the red end of the spectrum could be observed, but no dark bands were visible.   As the temperature was raised, the color of the light

[6] *Phil. Mag.* (6) **4**, 607, 1902.

falling on the slit of the grating became yellow, and the spectrum observed extended almost up to the blue. The visual method of observation was soon discarded, as selenium vapor absorbs chiefly in the blue, violet, and ultra-violet. Two photographs of the absorption spectrum of the vapor were then taken under the following conditions:

Experiment 1.—Photographs of the absorption spectrum at $540°$ and at $1070°$ C. were taken and examined. The low-temperature absorption spectrum does not show any bands, but indicates the presence of a general absorption increasing in intensity toward the violet, and becoming complete beyond $\lambda\,5500$. The spectrum extends from $\lambda\,7200$ to about $\lambda\,5500$. The photograph taken at $1070°$ shows the presence of absorption bands between $\lambda\,4700$ and $\lambda\,5300$. Also the absorption in the orange and yellow is very much diminished, and the spectrum extends from $\lambda\,7200$ to about $\lambda\,4650$.

Experiment 2.—This experiment was very similar to the previous one, the only difference being that the first photograph was taken when the temperature of the furnace was rising from $600°$–$700°$. The spectrum ($600°$–$700°$) extends to $\lambda\,4600$, and shows the presence of bands between $\lambda\,4600$ and $\lambda\,5300$. There is however much greater absorption in the region $\lambda\,5000$ to $\lambda\,5700$ at the low temperature ($650°$ C.) than at the high temperature ($1000°$ C.).

Series II

A combustion-tube containing 0.0015 grams of selenium was exhausted to a pressure of a fraction of a mm and sealed. Then the absorption spectrum was photographed at a temperature of $600°$ C. On examining the photograph it is found that there is complete absorption between $\lambda\,4000$ and $\lambda\,3600$, and absorption bands appear between $\lambda\,4000$ and $\lambda\,4500$. These bands are quite distinct from the SeO_2 bands previously described.

Series III

A very small quantity (0.0004 grams) of selenium was placed in a quartz tube, which was filled with hydrogen, and evacuated according to the method previously described. In the first place,

experiments were conducted at various temperatures far removed from the boiling point (680°) of the metal, and thus the absorption spectrum at different pressures could be determined. When the temperature of the furnace was 360° C., the absorption bands extended from about λ 3250 to λ 3750. Below λ 3250 there are no absorption bands, and for the small vapor pressure (corresponding to 360° C.) there are also no absorption bands between λ 3885 and the extreme red. When the temperature of the furnace was 380° C. the same absorption bands were photographed, but the intensity of the bands between λ 3580 and λ 3885 was stronger. The general absorption below 3250 was also much stronger. A photograph was also taken when the temperature of the furnace was 410° C. and it shows the presence of a few bands beyond 3580 in the ultra-violet. All the absorption bands (between λ 3200–λ 3600), which are visible in the 360° photograph are not present in the 410° photograph, because the absorption is too intense. However, the absorption bands in the region λ 3580–λ 3885 are very much stronger than in the lower temperature photographs. The approximate wave-lengths of the bands in the ultra-violet are: 3240, 3255, 3280, 3295, 3317, 3338, 3363, 3387, 3412, 3435, 3460, 3483, 3510, 3537, 3592, 3614, 3640, 3663, 3684, 3700, 3715, 3730, 3742, 3755, 3763, 3774, 3802.

The absorption lines 3640 $\left\{ \begin{matrix} 3635 \\ 3645 \end{matrix} \right\}$, 3663, 3684 are double lines, the wave-lengths given being the mean between the two components. The average width of the absorption bands between λ 3250 and λ 3580 is about 10 A°. At 600° C. all the selenium placed in the tube was in the state of vapor, and consequently experiments were made at this temperature, and also at much higher temperatures to determine the effect of temperature on the absorption spectrum of a constant mass of the vapor. The absorption spectrum at 600° C. shows the presence of absorption lines between λ 3700 and λ 4100, and complete absorption between λ 3700 and λ 2900. If photographs of the absorption spectra at 600° C. and 1070° C. are compared, it is found that they are almost exactly the same in the region λ 4000–λ 2400, but between λ 4000 and λ 4200 the absorption lines are stronger in the photograph

taken at the high temperature. The quartz tube containing 0.004 grams of selenium was finally heated to 1300° C., and the absorption spectrum photographed. The photograph shows the characteristic absorption bands of selenium vapor, and not the SeO_2 bands. There is also a distinct tendency for the absorption bands not to photograph quite as far in ultra-violet as before (600° C.). The main difference between the absorption spectrum at 1300° C. and at 600° C. is that the absorption bands extend much farther toward the red (to λ 4650) in the former.

CONSTANT-PRESSURE EXPERIMENTS

The pressure of the vapor inside the quartz tube was controlled by the current passing around the nickel wire, and the temperature of the coldest part of the apparatus was also measured. The description of the constant pressure experiments will be divided into two parts: (1) comparatively high pressures; (2) low pressures. Two photographs were taken at each pressure, one at a temperature of about 600° C., and the other at about 1000° C.

Experiments at Comparatively High Pressures

A $\begin{cases} \text{(1) 3.5 amperes passing through the nickel wire (temperature of coldest} \\ \text{part of apparatus 370° C.). Temperature of furnace} = 580° \text{C.} \\ \text{(2) Same conditions as (1) except that the temperature of the electric} \\ \text{furnace was 1020° C.} \end{cases}$

In the first photograph (temperature of furnace 580°) the absorption bands extend from λ 3885 to λ 4400. The light is completely absorbed between λ 3885 and about 2800. The absorption bands in the second photograph do not extend quite as far toward the ultra-violet as they do in the first. Also the absorption bands between λ 4200 and 4400 (i.e., toward the red) are more distinct in the second photograph (temperature of furnace 1020° C.).

B $\begin{cases} \text{(1) 3.8 amperes passing through the nickel wire (temperature of coldest} \\ \text{part of apparatus 420°). Temperature of furnace} = 600° \text{C.} \\ \text{(2) Same conditions as in (1) except that the temperature of the furnace} \\ \text{was 1015° C.} \end{cases}$

The absorption spectrum at 600° C. shows the presence of bands between λ 4200 and λ 4600. Below 4200 toward the ultra-violet

there is complete absorption, and above 4600 (to λ 7200) there are no absorption bands. The absorption spectrum at the high temperature shows slightly greater absorption in the violet, and the absorption bands above 4500 (toward the red) are more distinct.

C $\begin{cases} \text{(1)} \ \ 4.1 \text{ amperes passing through nickel wire (temperature of coldest part} \\ \qquad \text{of apparatus } 460°). \ \ \text{Temperature of furnace} = 600°. \\ \text{(2)} \ \ \text{Same conditions as (1) except that the temperature of furnace was} \\ \qquad 1010° \text{ C.} \end{cases}$

In the high- and low-temperature spectra, complete absorption occurs below λ 4500 (i.e., in blue-violet and ultra-violet). Absorption bands are visible between λ 4500 and λ 5160, and in each case a continuous spectrum is photographed between λ 5200 and λ 7200. The absorption bands between λ 4700 and λ 5200 are much more distinct in the photograph taken at the high temperature.

Another photograph was taken at a comparatively high temperature (940° C.), when 4.7 amperes were passing through the nickel wire (temperature of coldest part of apparatus 520°). The absorption spectrum shows the presence of bands between λ 4640 and λ 5200. The photograph between λ 4600 and λ 5200 consists of dark patches separated by fairly broad and lighter spaces. The absorption bands really consist of a large number of fine absorption lines. When 5.3 amperes were passing through the heating wire (temperature of coldest part of apparatus 583° C.) no absorption bands were visible. Below λ 5600 (i.e., in green, blue, etc.) there is complete absorption.

LOW-PRESSURE EXPERIMENTS

In these experiments a current of 2.5 to 2.8 amperes was passed through the heating wire, and the temperature of the coldest part of the apparatus was also measured. When the current was 2.5 amperes (temperature of coldest part of apparatus about 230° C.) weak absorption bands were photographed between λ 3200 and λ 3600, and the intensity of these bands rapidly increased as the current was raised to 2.8 amperes (temperature of coldest part of apparatus 280° C.). In the latter case the bands also extend from λ 3200 to λ 3800. The pressure was then kept constant (2.65 amperes through heating wire), and photographs of

the absorption spectra at 500° and 1100° C. were taken. In the latter case the absorption bands (λ 3200–3700), which were present at the low temperature, had almost competely disappeared. Similar experiments were made at a higher pressure (2.8 amperes through heating wire), when the temperatures of the furnace were 600°, 1100°, and 1200° C., respectively. At the highest temperatures the absorption bands between 3200 and 3700 were much weakened in intensity.

DISCUSSION OF RESULTS

The discussion of the relation between the absorption spectrum and the nature of the various molecular complexes is rendered very difficult by the lack of information concerning the densities of the vapor under the conditions employed. It is known that the vapor-density diminishes with increase of temperature, finally attaining a value corresponding to Se_2 at temperatures above 1500° C. On the other hand, the vapor-density, and the nature of the molecules present at low temperatures (300° C.) and pressures are unknown. It is perhaps allowable to postulate that at these comparatively low temperatures, the molecules are more complex (Se_4, Se_6, or Se_8), and if such is the case, there are reasons for considering the absorption bands between λ 3200 and λ 3700 to be due to molecules more complex than Se_2. These bands, which in all probability are due to Se vapor, make their appearance at temperatures in the neighborhood of 300° C., and also rapidly diminish in intensity with increase of temperature. When the pressure of the vapor corresponds to 2.65 amperes through the heating wire, the absorption bands actually disappear at about 1100° C., but when the pressure is higher (2.8 amperes) the bands do not disappear even at 1200° C. The absorption spectra of 0.0004 grams of selenium vapor at 600° C. and 1300° C. indicate that the breaking up of the more complex molecules into Se_2 causes the absorption bands to become more distinct toward the red, and brings out new bands not present at the lower temperature. Also complete absorption in the ultra-violet commences at a slightly higher wave-length. It can be stated without much doubt that the absorption in the ultra-violet is not appreciably diminished with increase of temperature. The evidence of the photographs seems to point to a slight

increase. At 1300° C., and 1.5 cm pressure (this would be the pressure of the Se vapor in the tube at 1300° on the assumption that all the vapor was diatomic) most of the molecules are diatomic, and probably the absorption bands between λ 3800 and λ 4700 are due to Se_2.

SUMMARY OF RESULTS

1. If the temperature of the selenium vapor is kept constant at 600°, absorption bands appear between λ 3200 and λ 3880, when the pressure is low. As the pressure increases there is complete absorption in the above region, and bands appear higher up the spectrum (i.e., toward the red). The same process is repeated as the pressure of the vapor is increased, until finally only the red end of the spectrum is let through.

2. The ultra-violet bands (λ 3250–λ 3800) diminish in intensity with increase of temperature, and for the low pressure corresponding to 2.65 amperes passing through the heating wire disappear at 1100° C. If the pressure is greater, the bands do not disappear altogether even at 1200° C.

3. For comparatively high vapor-pressures (i.e., complete absorption between λ 4200 and λ 2800), the effect of rise of temperature is to increase the intensity of the absorption bands toward the red and to cause the commencement of complete absorption in the blue, violet, or ultra-violet (depending on the pressure) at a point in the spectrum having a larger wave-length.

4. It is difficult to discuss the changes produced in the absorption spectrum by increase of temperature in relation to the corresponding changes of vapor-density, because of insufficient data. There are some reasons for regarding the bands between λ 3200 and λ 3800 as being due to molecules of greater complexity than Se_2 and the bands between λ 3800 and λ 4700 as being due to Se_2.

NOTE ON THE GROUPING OF TRIPLET SEPARATIONS PRODUCED BY A MAGNETIC FIELD[1]

By HAROLD D. BABCOCK

In recent papers on the Zeeman effect for chromium[2] and vanadium[3] attention was called by the writer to the grouping of the separations of the outer components of triplet lines. It was shown that for those metals the values of $\Delta\lambda/\lambda^3$ for triplets occur chiefly in two easily distinguishable groups. The completion of tables of magnetic separation for iron and titanium by King[4] has led to further inquiry along this line, which was subsequently extended so as to include all the data available. The additional material here discussed is found in papers by B. E. Moore on zirconium, yttrium, osmium, barium,[5] and thorium;[6] by W. Miller on manganese;[7] by H. M. Reese on nickel;[8] and by R. Jack on tungsten and molybdenum.[9]

The values of $\Delta\lambda/\lambda^2$ for the triplet lines of each metal were arranged in order of magnitude and a curve was drawn showing the frequencies of their occurrence. Lines whose classification or measurement was doubtful were omitted. As a considerable portion of the separations referred to the distance between the outer components instead of between the central and either one of the outer components, all the numbers were reduced to this system and the factor one-half applied at the end. The abscissas for the

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 57.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 52; *Astrophysical Journal*, **33**, 217, 1911.

[3] *Contributions from the Mount Wilson Solar Observatory*, No. 55; *Astrophysical Journal*, **34**, 209, 1911.

[4] *Contributions from the Mount Wilson Solar Observatory*, No. 56; *Astrophysical Journal*, **34**, 225, 1911.

[5] *Astrophysical Journal*, **28**, 1, 1908.

[6] *Ibid.*, **29**, 144, 178, 1909.

[7] *Physikalische Zeitschrift*, **7**, 896, 1906.

[8] *Astrophysical Journal*, **12**, 120, 1900.

[9] Göttingen Dissertation, 1908.
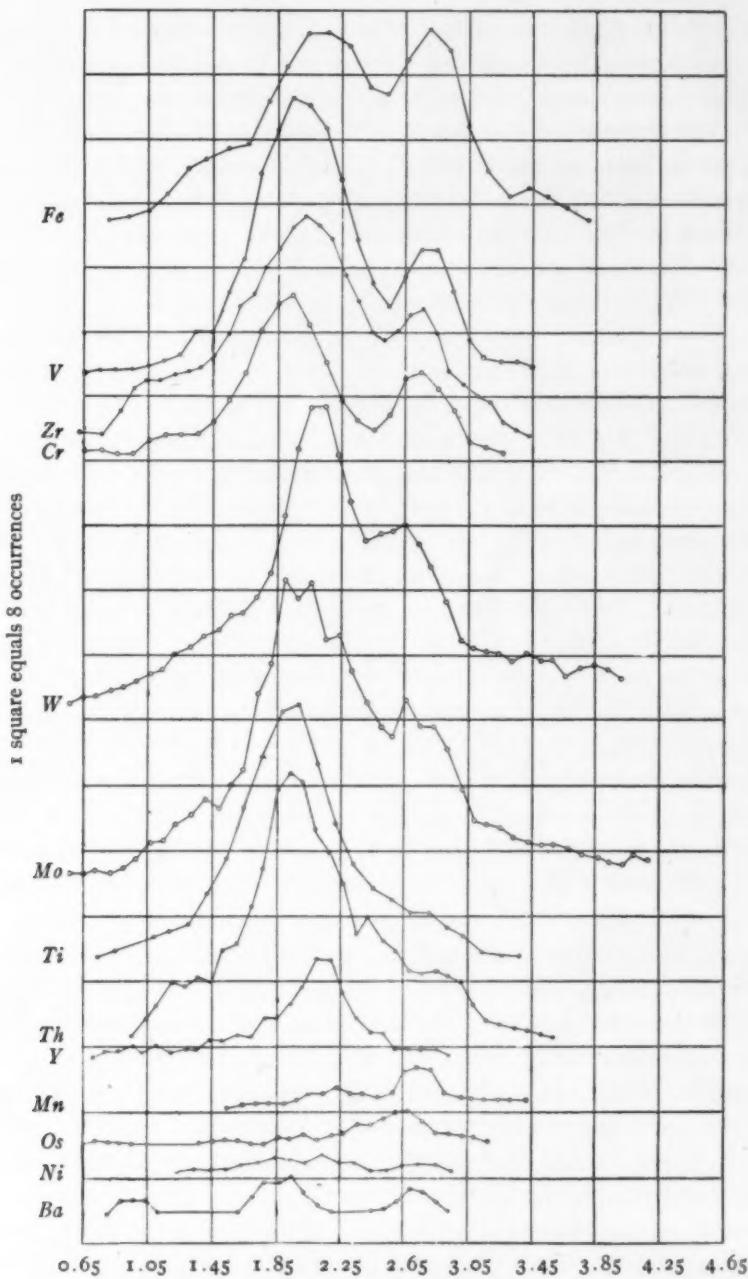
FIG. 1.—Grouping of Triplet Separations
Interval in $\Delta\lambda/\lambda^2$ equals 0.10.   Field 20,000 gausses

curves are equal intervals in $\Delta\lambda/\lambda^2$. A given ordinate was obtained by averaging the number of occurrences for its own abscissa with those for the two adjoining ones. As first drawn the curves related to the various field-strengths employed by different observers. The abscissas were accordingly reduced to a standard field of 20,000 gausses, making them directly comparable, and they are thus displayed in Fig. 1. The scales are, for the abscissas: interval in $\Delta\lambda/\lambda^2$ equals 0.10, one square being equal to four intervals; for the ordinates: one square equals eight occurrences.

The alignment of maxima and minima, first noticed for chromium and vanadium, is shown here extending in general to these other metals. The first maxima lie between the limits $\Delta\lambda/\lambda^2 = 1.80$ and $\Delta\lambda/\lambda^2 = 2.20$, while the second are included between the values 2.60 and 2.80. The abscissas corresponding to the two maxima are thus seen to have the ratio 2:3. Although some curves show the second maximum only slightly and others have only a suggestion of the first, none exhibits a distinctive grouping except barium. This metal has in addition to the two usual groups a third, the abscissas being in the ratio 1:2:3. Small weight attaches to the curves for osmium, barium, manganese, and nickel on account of the few triplet lines which have been measured in their spectra.

It is to be observed that the data studied here were collected by six observers working in five laboratories, and that the field-strengths were different and were measured by different methods. In addition it is likely that some lines are classified as triplets which are really more complex. So close a similarity among the curves is therefore remarkable, and a combination of the results should be of considerable interest. Accordingly the position of the minimum was carefully determined on each curve and the values of $\Delta\lambda/\lambda^2$ thus divided into two groups. The means for each group, weighted according to the number of lines upon which they depend, when combined yield as values of $\Delta\lambda/\lambda^2$, $1.892 \pm 0.014_7$ for group I, and $2.794 \pm 0.018_4$ for group II, the appended numbers being probable errors. Using the equation

$$\frac{\Delta\lambda}{\lambda^2} = \frac{e}{m} \cdot \frac{H}{4\pi v},$$

where H is the field-strength in C.G.S. units and v is the velocity of light, the resulting values of e/m are $1.783 \pm 0.013_8 \times 10^7$ and $2.633 \pm 0.017_4 \times 10^7$, the former being based upon measurements for 2043 triplets and the latter upon those for 827. Two-thirds of the larger value is 1.755 ± 0.116, which, when combined with the first, with weights proportionate to 2043 and 827, yields the final weighted mean 1.775 ± 0.0132. Table I is a summary of the work here indicated.

TABLE I

GROUPING OF TRIPLET SEPARATIONS

METAL	FIELD	GROUP I			GROUP II		
		Limits	Number of Lines	Mean $\frac{\Delta\lambda}{\lambda^2}$ H = 20,000	Limits	Number of Lines	Mean $\frac{\Delta\lambda}{\lambda^2}$ H = 20,000
Titanium......	17,500	1.00–2.25	214	1.876	2.25–3.20	25	2.872
Iron..........	16,000	1.20–2.00	139	2.079	2.00–2.90	108	2.908
Yttrium.......	24,400	1.70–3.10	56	1.955	3.10–4.00	5	2.702
Zirconium.....	24,400	1.70–3.00	307	1.821	3.00–4.00	91	2.760
Osmium.......	24,400	1.80–2.60	4	1.843	2.60–4.00	26	2.620
Barium........	24,400	2.00–2.50	18	1.860	2.50–3.50	8	2.700
Thorium.......	24,450	1.20–2.90	277	1.803	2.90–4.20	87	2.702
Manganese.....	23,850	2.00–2.85	11	2.160	2.85–3.70	20	2.750
Nickel........	28,300	2.00–3.40	12	1.970	3.40–4.25	2	2.760
Chromium.....	20,000	1.30–2.40	104	1.900	2.40–3.00	39	2.700
Vanadium.....	20,000	1.30–2.50	249	1.971	2.50–3.10	72	2.780
Molybdenum...	23,850	0.50–3.00	360	1.907	3.00–4.08	156	2.928
Tungsten......	23,850	0.80–2.85	292	1.863	2.85–4.80	188	2.726
			2043	$1.892 \pm 0.014_7$		827	$2.794 \pm 0.018_4$

$$\frac{e}{m} \quad 1.783 \pm 0.013_8 \times 10^7 \qquad 2.633 \pm 0.017_4 \times 10^7$$

It should be said that, before deciding upon the positions of the minima for these curves, they were drawn with various intervals in $\Delta\lambda/\lambda^2$, with and without the normal point ordinates described above; and the method of drawing herewith presented was selected as best representing the data. The minima were in general selected upon the original curves, before reduction to the standard field. The outer limits of the two groups are of little importance relatively, on account of the few occurrences there. A very few values of $\Delta\lambda/\lambda^2$ which were nearly one-half the value corresponding to the first maximum, or twice that value, were omitted from both groups.

The most important instance of this procedure is in the case of barium. The small distinctive group clustering around the value $\Delta\lambda/\lambda^2 = 1.90$ is not included in group I.

The appearance of a typical curve like that for chromium suggests a combination of two symmetrical overlapping curves. If this is the case, the positions of the maxima being the same for all the metals, but their relative heights different, the division of groups I and II at the minimum is not an equivalent process for

TABLE II

VALUES OF $\frac{e}{m}$ BY VARIOUS OBSERVERS

Färber*..............1.710×10⁷	Gmelin**..............1.771
Lohmann†........ { 1.750 / 1.720	Classen‡‡.............1.776
Gehrcke and v. Baeyer‡1.740	Bucherer¶¶............1.763
Stettenheimer††......1.791	Simon***..............1.865
Weiss and Cotton¶....1.767	Proctor†††............1.859
	Mean.............1.774

* *Annalen der Physik*, **9**, 886, 1902.

† Stettenheimer, Dissertation, Tübingen, 1907.

‡ *Verhandl. der Deutschen Physikalischen Gesellschaft*, **10**. Corrected by v. Baeyer, *Physikalische Zeitschrift*, **9**, 831, 1908.

†† Dissertation, Tübingen, 1907.

¶ *Journal de Physique* (4), **6**, 429, 1907.　　　¶¶ *Ibid.*, **9**, 760, 1908.

** *Annalen der Physik*, **28**, 1079, 1909.　　　*** *Annalen der Physik*, **69**, 589, 1899.

‡‡ *Physikalische Zeitschrift*, **9**, 764, 1908.　　　††† *Physical Review*, **30**, 53, 1910.

all cases. For the ratio of the number of values assigned to group I but really belonging to group II, to the number assigned to group II but belonging to group I, would depend upon the relative heights of the two maxima, as would the position of the minimum itself. When the ratio of the height of the second maximum to that of the first decreases, the minimum moves out toward greater values of $\Delta\lambda/\lambda^2$, increasing group I at the expense of group II. The mean value of $\Delta\lambda/\lambda^2$ for group I is thus raised and at the same time given greater weight, while the opposite happens to group II. For nearly all of the curves shown here the second maximum is lower than the first, so that if this source of error could be removed, the two values

of e/m upon which the final result depends would be more accordant.   It does not seem likely, however, that the final mean value would be much changed.

Table II is a collection of other determinations of e/m, the average of which is 1.774×10^7.   If the values of Proctor and of Simon be omitted, however, the average falls to 1.754×10^7, but the divergence of my result from this is only a little over 1 per cent.

MOUNT WILSON SOLAR OBSERVATORY
        June 1911

THE SOLAR PROMINENCE OF OCTOBER 10, 1910

By FREDERICK SLOCUM

A series of photographs of an interesting solar prominence was obtained with the Rumford spectroheliograph on October 10, 1910. Plates XIV and XV show some of the best views. All were taken in the light of the H-line of calcium except Figs. 2, 7, and 8, which were photographed in the $H\alpha$-line by Mr. Ellerman at the Mount Wilson Solar Observatory, and very kindly sent to me by him for comparison with my calcium images.

The prominence was first noticed on the plates of October 8, the first exposure of that date showing a bright mass 52,000 km high, extending from position angle $121°5$ to $125°5$, and a group of jets and filaments between $114°$ and $121°$, rising to the same height (Fig. 1, Plate XIV). Upon another plate, exposed at $5^h 59^m$ G.M.T., the mass had assumed the form of a cone, and the filament at $119°$ had increased to 70,000 km in height, curving over toward the apex of the cone.

No observations were made on October 9, as the electric power is not available during the daytime on Sundays, but the first plate of October 10 showed a great development (Fig. 3, Plate XIV). The prominence extended from $114°$ to $130°$, that is, from latitude $-24°$ to $-40°$, and reached a height of 105,000 km. The appearance is that of streams of gas rising from a great number of points on the surface, scattered over an area about 240,000 km in extent along a meridian. After ascending to some height most of the longer streams are inclined toward the south, while a few of the longer and most of the shorter streams are bent in the opposite direction. This may be due to horizontal currents in opposite directions at different levels, or the appearance may be produced by a local vortex. If the lower streams are in the background, as they seem to be, the direction of rotation would be clockwise, as seen from above, corresponding to the direction of terrestrial cyclones in the southern hemisphere.

PLATE XIV

1
Oct. 8
$5^h 59^m$ G.M.T.
Ca

2
Oct. 10
$2^h 50^m$
$H\alpha$

3
Oct. 10
$2^h 58^m 3$
Ca

4
Oct. 10
$4^h 28^m 2$
Ca

5
Oct. 10
$5^h 18^m 7$
Ca

6
Oct. 10
$5^h 35^m 1$
Ca

7
Oct. 10
$6^h 10^m 4$
$H\alpha$

8
Oct. 10
$12^h 0^m$
$H\alpha$
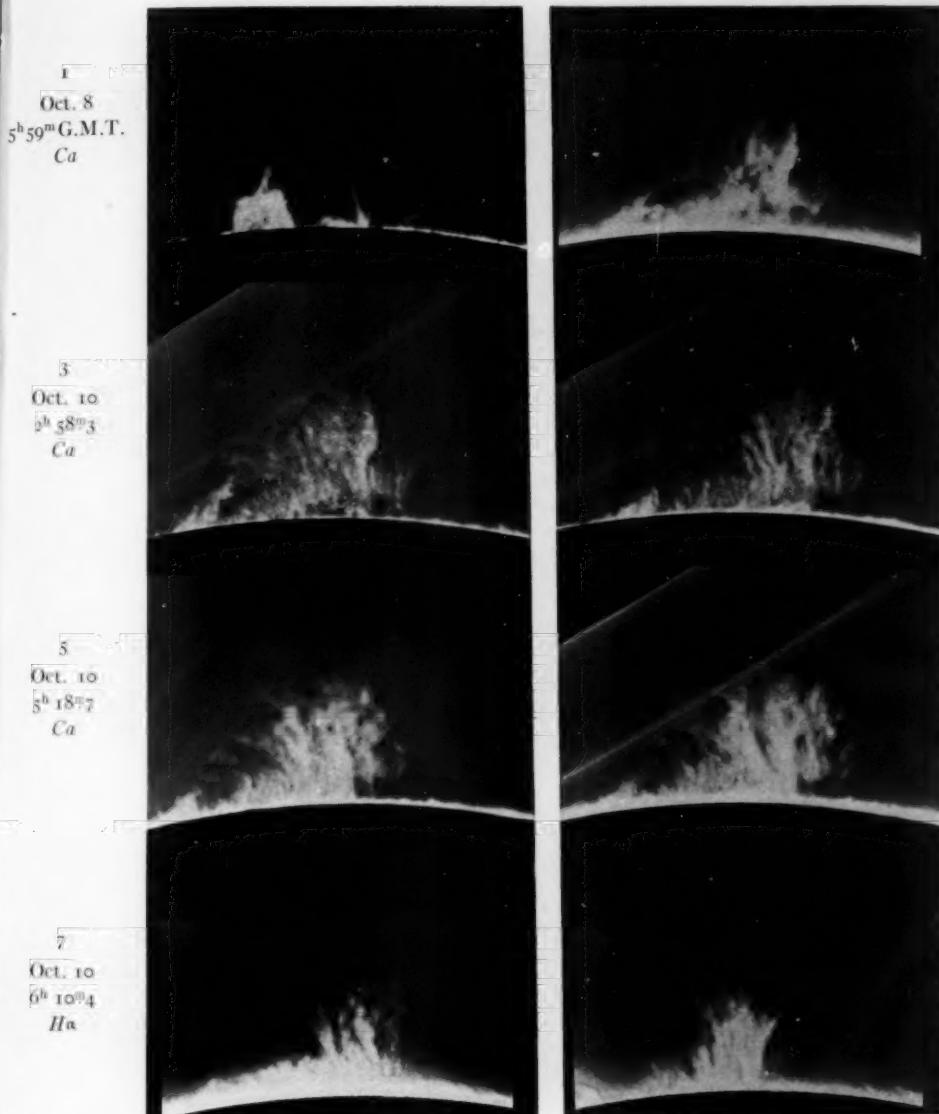
CALCIUM AND HYDROGEN SPECTROHELIOGRAMS OF SOLAR PROMINENCES ON
OCTOBER 8 AND 10, 1910
Scale: Sun's Diameter = 240mm
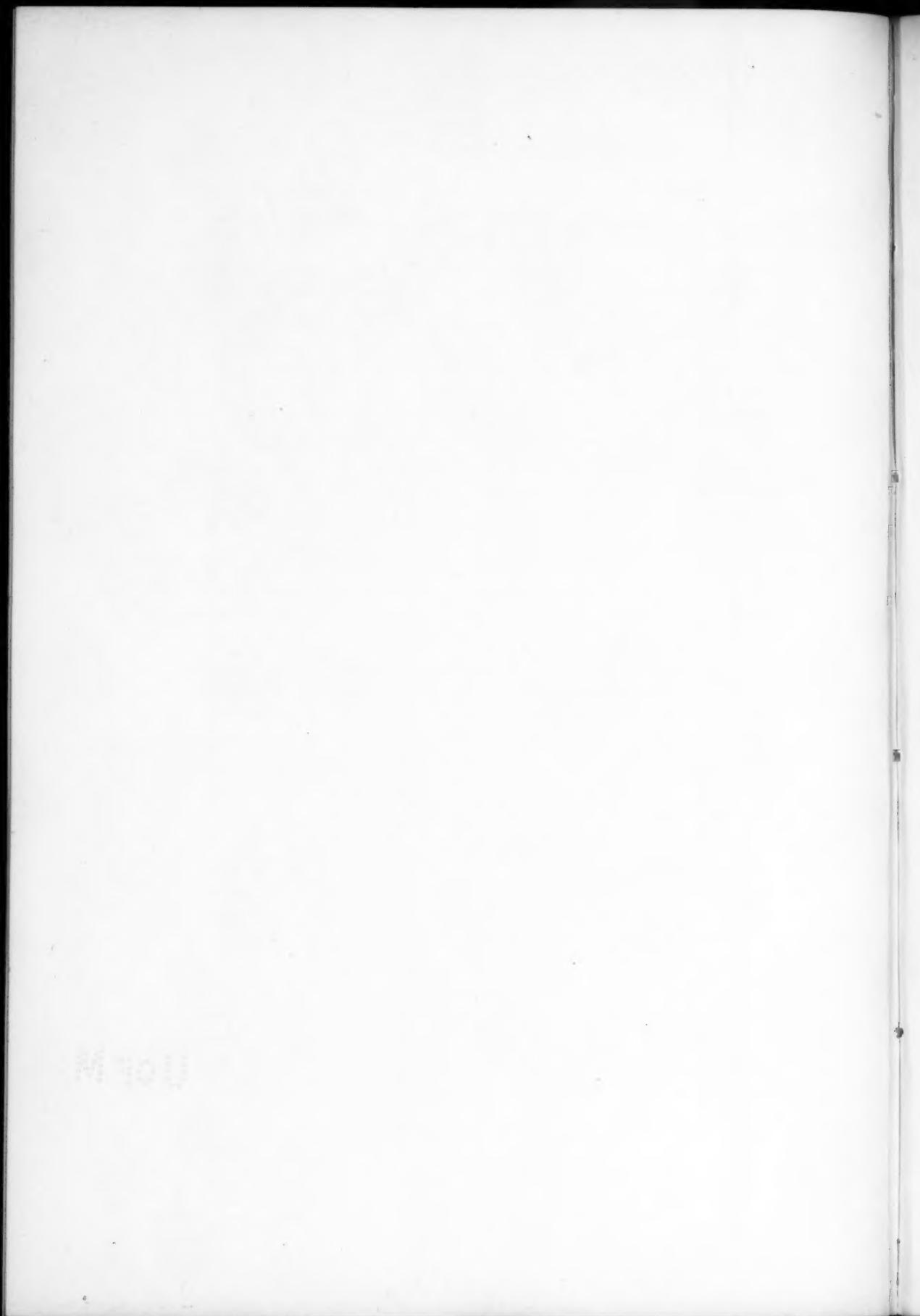
Mr. Ellerman's hydrogen image (Fig. 2, Plate XIV) was taken only eight minutes earlier than my calcium image (Fig. 3, Plate XIV). The general outline and dimensions of the two are approximately the same, but the details are quite different. The hydrogen prominence shows none of the filamentous structure which is the most conspicuous feature of the calcium image. This is not a general characteristic of hydrogen prominences, however, for Figs. 7 and 8, Plate XIV, show the filamentous structure to a very marked degree.

Between 2^h 58^m and 5^h 35^m G.M.T., ten calcium photographs of the prominence were obtained, three of which are reproduced in Figs. 4, 5, and 6, Plate XIV. No great change occurred during this interval, but many variations in the smaller details may be noted on all of the plates, even though some of them are separated by an interval of only 90 seconds. This shows the necessity of using the shortest possible exposure-time in prominence photography. The length of exposure for the calcium images in Plates XIV and XV, that is, the time required for the image of this prominence to pass across the first slit, was approximately ten seconds.

Some time after noon, 6^h G.M.T., the prominence became very active, but unfortunately not enough plates were secured, either here or at Mount Wilson, to trace all of the changes. From the Mount Wilson hydrogen photographs at 6^h and 12^h, G.M.T. (Figs. 7 and 8, Plate XIV), one might infer a continuous gradual decline of the prominence, but calcium photographs taken in the interval between these two show interesting activity. Six photographs were secured between 7^h 53^m and 8^h 6^m G.M.T., two of which are shown in Plate XV on a slightly larger scale than the figures of Plate XIV. The most interesting features of the prominence at this time were the central arch, the funnel beside it, and the long plume curving off to the right.

The arch was apparently decreasing in height at the rate of 23 km per second. Whether this formation is really an arch in the bright structure or whether it is a cloud of relatively dark vapor projected against the brighter prominence, it is impossible to decide. The sharp edges favor the latter alternative, while the faint structure seen under the arch may indicate the former.

A similar doubt exists in my mind in regard to the explanation of the round black dots which appear in both photographs of Plate XV. They may be either holes or absorption effects.

The change from the V-shape to the U-shape in the formation to the right of the arch in Plate XV is shown by intermediate plates to have taken place progressively. It presents the appearance of a vortex somewhat beyond the main part of the prominence, but I have no proof of vortical motion.

The plume evidently has its origin in the upper part of this vortex. If its form is due to the motion of particles, these particles must be attracted by the sun. This attraction may be electrical or may be purely gravitational, implying that the matter of which the plume is composed is heavier than the atmosphere in which it floats. In either case the plume differs from the main part of the prominence, in which the particles appear to be repelled, or to be lighter than the surrounding atmosphere, so that they rise like the flames from a terrestrial fire.

SPECTRUM OF THE PROMINENCE

At 5^h G.M.T. I obtained a series of photographs of the H and K region of the spectrum of the prominence. The second slit of the spectroheliograph was opened to its full width, 8 mm = 72 A, and exposures were made with the first slit across the prominence in an east-and-west direction. Between exposures the image of the prominence was moved 1 mm = $5''.3$ in declination. In this way twenty exposures were made.

The bright $H\epsilon$ line can be traced to a height of $10''$ in all of the spectra. The H_2 and K_2 lines of calcium at the limb show the normal chromospheric appearance with maximum widths of 1.03 and 1.31 A respectively. Beyond the limb the lines taper down for a distance of $15''$ to $18''$ and then maintain an approximately uniform width of 0.92 A for the H_2 line and 0.95 A for the K_2 line out to the limit of the prominence. In the chromosphere the K_2 line rises to a somewhat greater height than the H_2 line, but in the prominence they are equal in length. In intensity the K_2 line is stronger than the H_2 line, but both vary greatly in different

PLATE XV
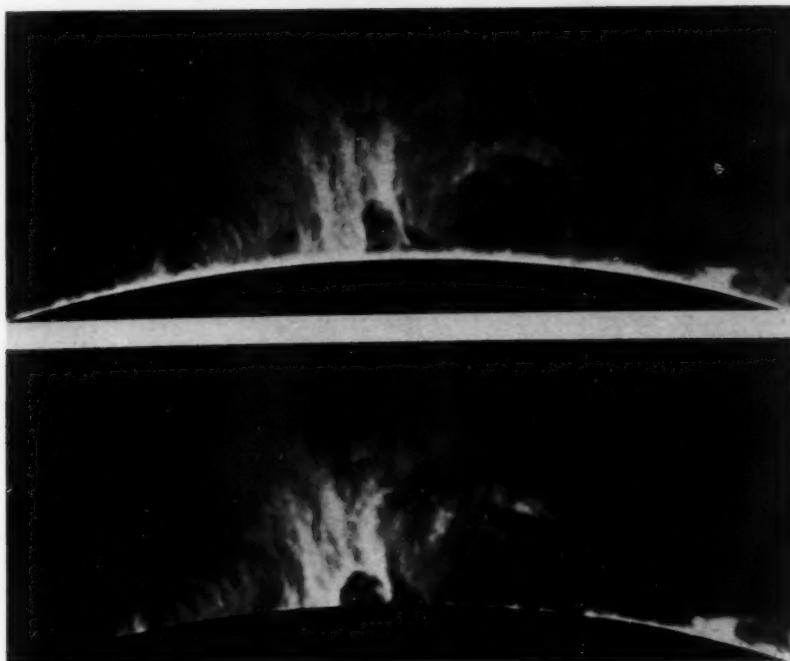
CALCIUM SPECTROHELIOGRAMS OF SOLAR PROMINENCE ON OCTOBER 10, 1910
Scale: Sun's Diameter = 340mm

parts of the prominence, the variation apparently being somewhat greater in the H than in the K line.

Measurements of the calcium lines with respect to the neighboring metallic lines of the sky spectrum were made. The lines of the latter are weak in comparison with the emission lines of the prominence and the results are not conclusive, but they seem to indicate that there is no appreciable displacement of the H_2 and K_2 lines as a whole, but that local displacements up to ± 0.15 A occur in both lines.

The absorption lines H_3 and K_3 appear fine and sharp at the sun's limb and are displaced 0.13 A toward the blue with respect to the H_2 and K_2 lines. Both the H_3 and K_3 lines can be traced throughout the length of the H_2 and K_2 lines, their average widths being 0.21 A and 0.19 A, respectively; the K_3 line thus appears narrower than the H_3, while the K_2 line is wider than H_2. The absorption lines are not straight, but follow an irregular sinuous course within the emission lines, the local relative displacements amounting to ± 0.20 A.

If these displacements are manifestations of the Doppler effect, they correspond to velocities of about 15 km per second in the line of sight. Such velocities would be of the same order as the transverse movements shown by the spectroheliograms; but if the vapor which produces the absorption lines exists only at a high level, as has generally been assumed, the movements indicated, at least those which cause the displacements near the limb of the sun, must be entirely independent of the prominence.

If, for example, we assume that the absorbing vapor is at a height of $2'$ or about 43,000 km, and that the prominence is exactly at the limb, the material producing the H_3 and K_3 lines will be, for different parts of the prominence, from 90,000 km to 170,000 km nearer to the observer than the bright vapor which produces the H_2 and K_2 lines. For an absorbing stratum at a height of $3'$ the figures would be 215,000 km for lines formed at the northern limit of the prominence and 241,000 km for those at the southern limit.

It is not at all certain, however, that motion in the line of sight is the only cause that will explain the displacements in this case.

W. Michelson[1] and A. Cotton[2] have shown that changes either in density or refractive power, or transverse movements of any transparent medium through which light passes, will produce displacements in the lines due to the source of light, and it is possible that some such process may be concerned in producing the irregular relative displacements of the emission and absorption lines of calcium.

On October 11 the site of the prominence was occupied by a group of prominences about 40″ in height, extending continuously from position-angle 92° to 134°.

YERKES OBSERVATORY
    May 22, 1911

[1] "On Doppler's Principle," *Astrophysical Journal*, **13**, 192, 1901.

[2] "On Doppler's Principle in Connection with the Study of Radial Velocities on the Sun," *ibid.*, **33**, 375, 1911.

THE WIDENING OF THE HYDROGEN LINES BY HIGH PRESSURES

By R. ROSSI

It has been known for some years that when an electric arc burns between electrodes of certain metals in an atmosphere of hydrogen, and when the light is examined with a spectroscope, the hydrogen lines are brilliantly seen in addition to the metallic spectrum.[1] The lines are rather broad, with diffused edges, which shade off gradually; only the first four or five members of the hydrogen series can be noticed; the more refrangible ones being probably too wide and too faint to impress the photographic plate.

In the course of some experiments on the effect of pressure on metallic arc spectra in an atmosphere of hydrogen[2] it was noticed that the lines of that gas were much broadened by high pressure, sometimes to the extent of some hundreds Ångström units.

The following work is a rough attempt to find the rate of widening with pressure. The source of light was a copper arc burning in hydrogen at pressures ranging from $\frac{1}{4}$ to 26 atmospheres (absolute). Observations were confined to the more intense lines, viz., $H\alpha$, $H\beta$, $H\gamma$, and $H\delta$. Owing to the haziness of the lines a small-dispersion spectrograph was chosen, the distance on the photographic plate from $H\alpha$ to $H\delta$ being only 1.6 cm.

The widths were measured with a Kayser measuring machine, the middle of the shadings on each side of a line being taken as edges.

A difference in the time of exposure or development will give different values for the widths of the lines, if measured in this way, owing to changes of intensity on the plate. To overcome this difficulty in part, at least, several photographs were taken at each pressure, each with a different exposure; and the measure-

[1] Crew and Basquin, *Proc. Amer. Acad.*, **33**, 18, 1898; and Basquin, "The Spectrum of Hydrogen Given by the Metallic Arc of Tin, Copper, Silver, etc.," *Astrophysical Journal*, **14**, 1, 1901.

[2] *Phil. Mag.* (6), **21**, 499, 1911.

ments were then taken on a set of plates on which the average
intensity of the copper lines had remained the same. At low
pressures, when the lines were still comparatively narrow, their
width was estimated from the widths of the copper lines at atmos-
pheric pressure.

As the pressure increases, the lines are broadened out, especially
the more refrangible ones, which finally melt into one another, thus
rendering impossible a measurement of their width at high pres-
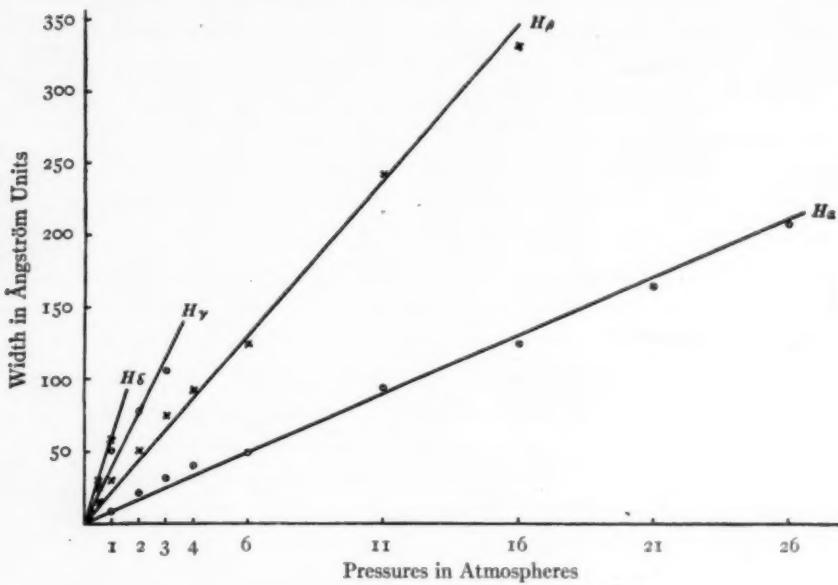
DIAGRAM I

sures. They all seem to broaden out symmetrically, with the
exception of Ha, which broadens out more toward the violet end
of the spectrum. This is especially noticeable at the higher pres-
sures. No reversals seem to take place, but the small resolving
power of the instrument used may not enable one to notice them.
There are no striking changes in the relative intensity of the lines,
only a slight enhancement of Ha. The accompanying table gives
the widths found at the various pressures. These values are
plotted in Diagram I, widths as ordinates, pressures as abscissas.

WIDTHS IN ÅNGSTRÖM UNITS†

Pressures in Atmospheres	¼	½	1	2	3	4	6	11	16	21	26
H_a	..	..	8*	(21)	31	39	48	92	121	163	206
H_β	..	16	30	50	74	91	124	241	(330)	..	..
H_γ	8*	24	50	77	105	..	..	..	..	..	..
H_δ	8*	29	58	..	..	..	..	..	..	..	..

†An asterisk (*) indicates that the width was estimated from the widths of the copper lines at atmospheric pressure. Figures in parentheses denote doubtful readings.
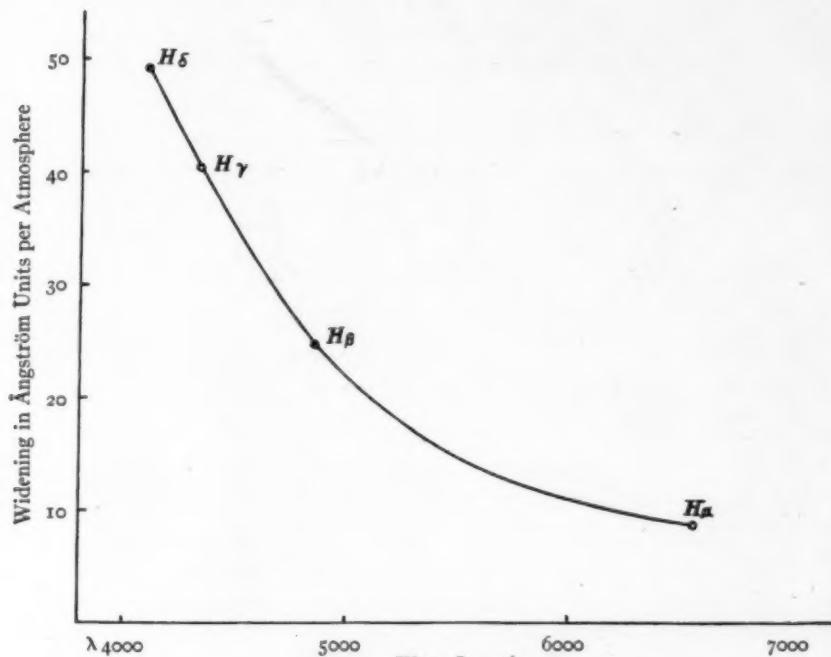
DIAGRAM II

Within the limit of experimental error, the width increases linearly with the pressure; it is interesting to note how this law, found by Michelson for low pressures, in the spectrum of the hydrogen vacuum tube, holds also at these high pressures. It is also seen from Diagram I how the rate of widening with pressure

is larger for the more refrangible lines. The mean values of the broadening in Ångström units per atmosphere are respectively:

$H\alpha$	$H\beta$	$H\gamma$	$H\delta$
8.69	24.7	40.4	49.3

Too much weight should not be attached to the last two figures, the measurements for $H\gamma$ and $H\delta$ being taken over too small a range of pressures. These rates of broadening are plotted against wave-lengths in Diagram II. These four values are not strictly comparable, owing to the different sensibility of the photographic plate for different radiations (tending to make the first values smaller, compared with the others) and the slight changes in relative intensity of the lines (tending to make the first value larger). Assuming them to be comparable, we find that for hydrogen the broadening varies as the inverse third or fourth power of the wave-length.

I express my thanks to Professor Rutherford and Professor Schuster for their interest in this research, and for placing the necessary apparatus at my disposal.

THE RADIAL VELOCITY OF α *CYGNI*

By OLIVER J. LEE

When the binary character of *a Cygni* was announced,[1] the suggestion was made that the H and K lines of calcium, which in this star are strong and narrow, deserved special investigation. A series of one-prism plates was made with the Bruce spectrograph during the summer of 1910. Most of these spectrograms were taken on the "Seed 23" emulsion and all were fully exposed in the region from λ 3900 to λ 5000. These plates, with 3 others taken several years ago, in all 19 plates, were measured. The calcium lines did not show any anomalous behavior and the publication of the results has been deferred.

In a paper[2] published last winter Neuimin and Belopolsky find apparently real residuals when the velocities derived from the hydrogen and helium lines are compared with those obtained from the metallic lines. From 11 plates Neuimin finds a mean difference for metallic lines minus $H(\beta,\gamma,\delta)$ of $+9.1 \pm 1.2$ km, and Belopolsky from 5 of the same plates computes the residual for metallic lines minus $H(\beta, \gamma, \delta, \epsilon)$ and He λ 4472 of $+7.1 \pm 0.9$ km. Recently Mr. Frost called my attention to these papers and suggested that I examine my measures concerning this point.

Although *a Cygni* shows about 70 measurable lines on our one-prism plates, only 14 have been considered in this paper. Of these 10 are metallic lines, mostly enhanced, and so situated in the spectrum that there can be no doubt of their purity. The other 4 are the β, γ, δ, and ϵ lines of hydrogen. The helium line λ 4472 is too weak and diffuse on our plates to be relied upon and hence has not been included. The accompanying table (p. 304) gives all the usual data for these plates.

In the next table (p. 305) I have followed to some extent the arrangement used in the *Mitteilungen* for the sake of simplifying the comparison of results.

[1] *Astrophysical Journal*, **31**, 176, 1910.

[2] *Mitteilungen der Nicolai-Hauptsternwarte zu Pulkowo*, No. 38, 1911.

Plate	Date	G.M.T.	Taken by	No. Lines	Velocity	Quality of Plate
					km	
IB 1074.........	1907 June 1	21^h39^m	Fox	9	− 2.5	v.g.
1075.........	June 1	21 53	Fox	13	− 3.7	v.g.
2177.........	1909 Nov. 8	15 18	L.	12	−10.9	v.g.
2342.........	1910 May 20	21 38	L.	12	−10.4	v.g.
2347.........	May 23	20 32	B.	12	− 8.7	Overexp.
2360.........	May 30	21 30	B.	14	− 6.4	v.g.
2369.........	June 6	21 45	M.	11	− 3.8	g.
2376.........	June 10	21 15	L.	11	− 8.3	g.
2409.........	June 27	21 47	M.	12	− 5.4	Overexp.
2418.........	July 4	19 42	L.	12	− 4.5	v.g.
2444.........	July 25	16 12	L.	10	− 4.7	v.g.
2450.........	July 29	16 19	B.	14	− 9.1	v.g.
2459.........	Aug. 1	17 17	L.	11	−11.6	v.g.
2487.........	Aug. 19	15 08	B.	12	− 5.2	v.g.
2490.........	Aug. 25	15 54	B.	14	− 1.9	v.g.
2497.........	Aug. 27	14 39	L.	14	− 7.3	v.g.
2500.........	Sept. 5	14 21	B.	11	− 7.6	v.g.
2504.........	Sept. 19	13 00	L.	14	− 9.3	v.g.
2750.........	1911 June 29	19 53	L.	13	+ 2.8	v.g.

B = Barrett, L = Lee, M = S. A. Mitchell.

The average magnitude of the differences given in the line Metal−Hydrogen is +2.32 km. A glance at the range of the velocities given by the hydrogen lines on each plate shows this difference to be well within the limit of observational error.

The average of the probable errors for the mean of the metallic lines is ±1.01 km. The corresponding average for the hydrogen lines is about twice as large when computed and probably 3 to 4 times as large in reality.

The differences of the mean of all the lines measured on a plate from the mean of the lines representing each element were averaged for the 19 plates. They are:

Mean −*Fe*	−1.04 km
Mean −*Ca*	−0.09 km
Mean −*Mg*	−2.09 km
Mean −*Ti*	−0.52 km
Mean −*Cr*	−0.92 km
Mean −*H*	+1.42 km

These residuals cannot be regarded as anything but accidental errors.

A discrepancy is found by Neuimin in the wave-length of the *Mg-Cr* blend at λ 4352 and is corrected by him by assuming

RADIAL VELOCITY OF α CYGNI AS DERIVED FROM DIFFERENT ELEMENTS

Elem.	Wave-Length	1074	1075	2177	2342	2347	2360	2369	2376	2409	2418	2444	2450	2459	2487	2490	2497	2500	2504	2730
		km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km
Fe	4045.035	−16	−13	+ 5	−28	……	−24	……	……	−10	−14	……	− 8	……	− 7	+ 7	− 8	− 6	− 9	− 4
	4508.455	−26	−24	+ 1	−31	−21	−19	−20	−30	……	−16	− 4	−20	−14	− 4	+ 2	− 5	− 3	− 2	− 5
	4515.508	……	……	+ 3	−14	−19	−16	−13	−17	……	−18	− 5	−18	−13	− 9	+ 5	− 9	− 4	+ 6	−13
Ca	K 3933.825	−14	−12	+11	−22	−20	−19	−26	−20	−16	−14	−13	−13	−15	− 7	− 7	− 6	− 7	− 3	−14
	H 3968.625	−16	−10	− 6	−23	−24	−23	−20	−24	−20	−19	−15	−16	−15	− 8	− 6	− 9	− 6	− 0	−12
Mg	4481.400	−14	−10	+ 9	−25	−21	−21	−20	−24	−15	−14	−12	−18	−11	− 5	+ 4	−10	0	− 6	− 9
Ti	4501.445	−22	−24	……	−19	−24	−18	−15	−23	−19	−16	……	−17	−12	……	+ 1	− 2	……	−10	−12
	4563.939	……	−28	+10	−25	−25	−22	……	−27	……	−21	……	−11	−24	……	+ 7	+ 3	……	+ 6	−12
Cr	4558.827	−21	−21	+10	−24	−26	−27	−13	−22	−12	−18	−10	−14	−12	……	+ 4	−14	− 3	+ 2	− 6
	4588.381	……	……	+ 5	……	……	−23	……	……	−15	……	……	−21	−24	……	+ 4	− 5	− 6	+ 3	……
H	3970.213	−12	−14	+ 1	−20	−17	−14	−19	−12	−14	− 7	− 7	− 6	−24	− 5	+ 4	− 2	− 3	0	0
	4101.900	−17	−14	+ 6	−39	−31	−21	−20	−28	−17	−17	−21	−18	−20	− 9	− 3	−11	−11	− 5	−10
	4340.634	−17	−18	+ 6	−31	−31	−16	−16	−22	−27	−18	−22	−16	−19	−11	−13	−13	−11	−11	− 7
	4861.527	……	−19	+ 5	……	……	−28	−27	……	−27	……	−16	−28	−29	−17	− 3	−11	− 9	−15	−19
Means of metallic lines ……		−18.1	−19.2	+ 5.4	−23.4	−22.5	−21.1	−18.1	−23.2	−16.1	−16.7	− 9.8	−15.6	−14.9	− 5.6	− 1.7	− 6.5	− 4.4	− 1.9	− 9.7
Means of hydrogen lines ……		−15.3	−16.2	+ 0.2	−30.0	−26.3	−21.0	−18.3	−20.7	−21.2	−14.0	−16.5	−17.0	−23.0	−10.5	− 3.8	− 9.0	− 7.7	− 7.8	− 9.0
Metal−hydrogen……		− 2.8	− 3.0	+ 5.2	+ 6.6	+ 3.8	− 0.1	+ 0.2	− 2.5	+ 5.1	− 2.7	+ 6.7	+ 1.4	+ 8.1	+ 4.9	+ 2.1	+ 2.5	+ 3.3	+ 5.9	+ 0.7
Means of all lines …		−17.1	−18.3	+ 3.7	−25.1	−23.5	−21.1	−18.2	−22.5	−17.8	−16.0	−12.5	−16.0	−17.8	− 7.2	− 2.3	− 7.2	− 5.3	− 3.6	− 9.5
Reduction to sun …		+14.64	+14.62	+14.60	+14.74	+14.83	+14.70	+14.40	+14.18	+12.30	+11.51	+ 7.80	+ 6.91	+ 6.15	+ 1.95	+ 0.37	− 0.06	+ 2.32	+ 5.71	+12.28
Radial velocity ……		− 2.5	− 3.7	−10.9	−10.4	− 8.7	− 6.4	− 3.8	− 8.3	− 5.4	− 4.5	− 4.7	− 9.1	−11.6	+ 5.2	+ 1.9	− 7.3	− 7.6	− 9.3	+ 2.8

intensities of 2 and 5 respectively for the two components instead of 5 and 5 as given by Rowland. There is, however, an iron line at λ 4351.94 which is missing in the arc and rises in the spark to intensity 2 on the scale of 10 for the strongest lines present. Concerning this line Sir Norman Lockyer and Mr. Baxandall say:[1]

In stars of the solar type the line is probably of a complex origin, *Cr* 4351.93, *Mg* 4352.08, and p *Fe* 4351.93 all being involved. In higher temperatures stars like *a Cygni*, *Sirius*, and *Rigel* there is abundant evidence in favor of a proto-*Fe* origin and little or none for either chromium or magnesium. Thus, other lines of *Cr* and *Mg*, which are similar in intensity and behavior in their respective spectra to those mentioned above, are all unrepresented in these stellar spectra, whereas all the enhanced *Fe* lines of similar intensity and behavior to the line 4351.93 are strongly represented in the same stellar spectra.

The wave-length 4294.273 has been used for the blend of *Ti* 4294.204, intensity 2, and *Fe* 4294.301, intensity 5. A comparison of these lines in the arc and spark[2] shows that while the intensity of the *Ti* line changes from 4 to 6, the *Fe* line is unaffected. Hence the adopted wave-length is probably a little too large. A few of the lines used by Neuimin, for example $\lambda\lambda$ 4290.377, 4303.337, 4308.081, and 4338.084, are known to have closely neighboring lines that are enhanced at the higher temperatures. It is not probable that the elimination of a few doubtful lines would have materially affected the mean. The precaution has been taken, however, of using chiefly enhanced metallic lines and in every case lines that are sufficiently isolated from other lines to be unaffected by them.

Isolated faint companion lines were seen and measured on several plates, but only on one plate were they consistent enough to be regarded as real. This exception is No. 2360, which shows a satellite at the lines γ, δ, ϵ, and *Mg* 4481 about 0.6 Å. U. toward the red. A re-examination of our plates was made to see if faint companions to the stronger lines used in measurement could be detected on more of the plates. Could it be shown that such satellite lines occur repeatedly, this might furnish an explanation of the anomaly in velocity suggested by the observations of Neuimin and Belopolsky,

[1] *Proc. R.S.*, **74**, 260, 1904.

[2] *Astrophysical Journal*, **19**, 325, 330, 1904.

for obviously a faint line lying close on the edge of a heavier line will vitiate measures of the center of this line. Several pairs of plates, comparable in point of density and grain-structure, have hydrogen lines which differ slightly in width and in sharpness of the edges.

The following conclusions may be drawn:

1. The present observations do not confirm the conclusion reached by Neuimin and Belopolsky and the mean residual from 19 plates of $+2.32$ km cannot safely be interpreted as real.

2. The discrepancy found by them may be due to the complexity in the hydrogen lines as indicated.

YERKES OBSERVATORY
    August 1911

RESIDUAL RAYS OF SELENITE

By H. M. RANDALL

In a recent paper J. Koch[1] has reported the results of a new determination of the wave-length of the residual rays ("Reststrahlen") from selenite. The method makes use of a Jamin interferometer by means of which a direct comparison is made between corresponding numbers of interference bands due to the "Reststrahlen" and to the sodium line $\lambda = 0.58948\,\mu$ (*vacuo*). The following results were obtained:

$$(1)\quad \lambda = 8.6795\,\mu\ (vacuo)\ \text{(mean of 10)}$$
$$(2)\quad \lambda = 8.6770\,\mu\ (vacuo)\ \text{(mean of\ \ 5)}$$
$$(3)\quad \lambda = 8.6789\,\mu\ (vacuo)\ \text{(mean of\ \ 5)}$$

Mean $\quad \lambda = 8.6787\,\mu$ (*vacuo*)

The relatively close agreement of the various values is interesting and raises the question as to whether other methods will yield the same result; that is, whether the "Reststrahlen" from selenite may be employed as a standard wave-length in the infrared region. Energy-curves of this radiation have been obtained accordingly by using both the grating and the prism method. As these methods are familiar, the experimental details will be sufficiently indicated by the accompanying diagram, Fig. 1. S, the source of the radiation, is a 220-volt Nernst lamp, whose image is focused by the silvered mirror M upon the slit S', of the mirror spectrometer after three reflections at the polished selenite surfaces g, the angle of incidence being about 45°. M_1 and M_2 are silvered mirrors 10 cm in diameter and of 50 cm focal length, while L is a plane Rowland grating with 40 lines per mm. The spectrometer was made by Fuess and has been previously described.[2] The linear thermopile T was of the Paschen type[3] and is used in connection

[1] *Annalen der Physik*, **26**, 974, 1908.

[2] E. Giesing, *Annalen der Physik*, **22**, 333, 1907.

[3] F. Paschen, *ibid.*, **33**, 736, 1910.

with a Paschen galvanometer, with which a deflection of 1 mm corresponded to a current of 0.7×10^{-10} amperes, the scale being approximately 2.5 m from the galvanometer. The deflections of the galvanometer were pro-portional to the current throughout the length of the scale. The slits S and S' were kept equal and gradu-ally increased in width till sufficient r a d i a t i o n passed through to give satisfactory deflections of the galva-nometer. A relatively wide slit, 1.7 mm, was found nec-essary. This corresponds to a spectral region of about 800 Å.U. The wave-length, λ, is given by the equation ($\lambda = C \sin \theta$), C being deter-mined by using the He line S λ 5875.870 in the 30th and 40th orders. C was found to be 504817 Å.U.

FIG. 1

Fig. 2 represents the energy-curves to the right and left of the undeviated image, the abscissas are the spectrometer readings and the ordinates the galvanometer-throws when the shutter before the slit S is removed. The wave-length corresponding to the center of mass of the triangles is $\lambda = 86940$ Å.U. (*vacuo*). A second independent determination gave $\lambda = 86950$. These values are in accord with that of Aschkinass[1] which was 8.69 μ.

The grating was then replaced by a fluorite prism, and the slits were narrowed to 0.28 mm. In this case the slit-width cor-responded approximately to 180 Å.U. The curves of Fig. 3 were obtained with this arrangement. The observed throws of the galvanometer are indicated by the points of the lower curve. These have been increased by multiplying by the proper factor to

[1] *Annalen der Physik*, 1, 42, 1900.
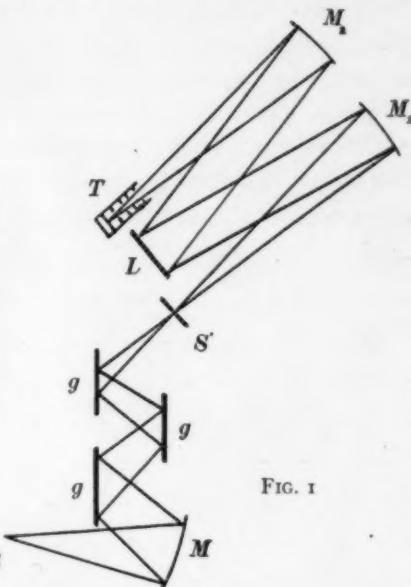
compensate for the absorption of the fluorite,[1] which is large in this region, and the upper curve represents the values which would have been obtained had there been no absorption. This curve gives $\lambda = 86785$ Å.U. (*vacuo*) for the wave-length corresponding to the center of mass of the triangle. This is also quite accurately the value of the wave-length corresponding to the maximum of the curve. It will be noticed that this result is in close agreement with those of Koch, indicating the correctness of the determinations of Paschen on the dispersion and absorption[2] of fluorite in this
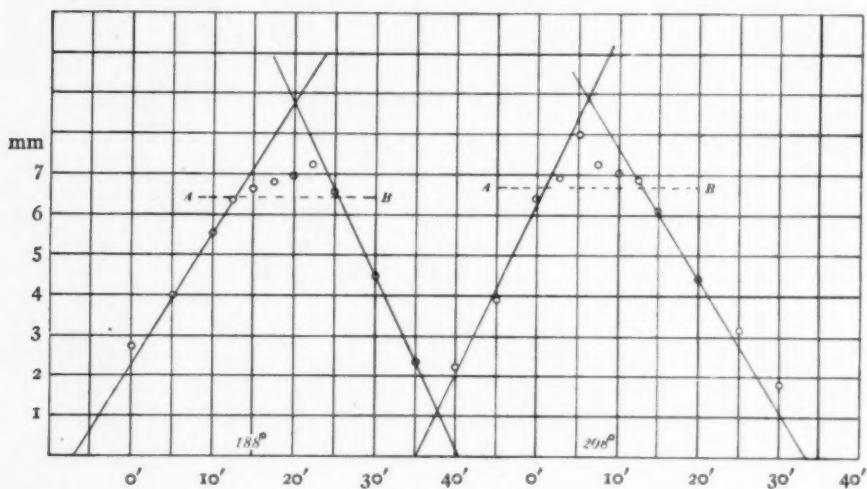
Fig. 2

region. While the value obtained by the grating is perceptibly larger than that given by the prism, due possibly to the alterations in the energy-distribution of the spectrum which a grating may introduce, it is interesting to observe that the wave-lengths obtained from those parts of the bands carrying the maximum energy are nearly the same in the two cases, being in fact also in close agreement with the values of Koch. Thus, if the values of λ are obtained from the intersections of the lines AB with the curves, the following results are obtained:

[1] F. Paschen, *Sitzungsberichte der K. preuss. Akademie der Wissenschaften*, I, 417, 1899.

[2] F. Paschen, *Annalen der Physik*, **53**, 301, 812, 1894.

Grating $\lambda = 86793$ Å.U. (*vacuo*)
Prism $\lambda = 86770$ Å.U. (*vacuo*)
while from Koch $\lambda = 86787$ Å.U. (*vacuo*).

It is to be noted also that the approximate breadth of the band in the case of the prism is o. 5 μ and in the case of the grating o. 6 μ, values which are in substantial agreement with the value o. 5 μ obtained by Koch from visibility-curves.

While the values from the energy-curves by either of the methods here used may be repeated under definite conditions with variations not exceeding 20 Å.U., still the fact that the different methods
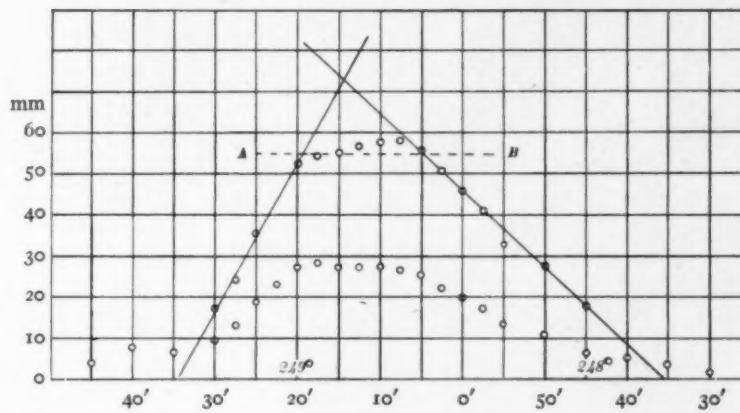

FIG. 3

give appreciably different results and also the fact that the band seems to have a rather broad maximum make it unsuitable for a standard of wave-length. In fact, the form of this somewhat broad maximum suggests the possibility of a double maximum for the residual rays of selenite in this region. The data do not warrant, however, any positive conclusions in this respect.

These data were obtained in the Physical Laboratory of the University of Tübingen and the writer wishes to express here his deep obligations to its director, Professor F. Paschen.

PHYSICAL LABORATORY
UNIVERSITY OF MICHIGAN
August 1911

NOTE ON THE ZEEMAN EFFECT FOR CHROMIUM

By J. E. PURVIS

In the *Astrophysical Journal* for April 1911 (**33**, 217) a description is given by H. D. Babcock of the measurements of the constituents of a series of chromium lines in the visible regions of the spectrum. He also gives a table comparing his values of $\frac{d\lambda}{\lambda^2} \cdot 10^8$ for four chromium lines with those measured by myself,[1] by W. Hartmann,[2] and by W. Miller.[3]

The differences are considerable, and I have remeasured the separate constituents of the four cited lines which were photographed on another plate about the same time as those which were measured and quoted in my earlier paper. I have reduced the determinations to a field-strength of 23,850 C.G.S. units so as to compare the numbers with the others, and the results of a comparison of the triplets are given in the following table:

COMPARISON OF SEPARATIONS OF TRIPLETS

$$\frac{d\lambda}{\lambda^2} \cdot 10^8 \text{ for 23,850 C.G.S. Units}$$

λ	Purvis. Earlier Measurements	Purvis. Later Measurements	Miller	Hartmann	Babcock
4646.39	+0.93 0 −0.93	+0.92 0 −0.92	+1.31 0 −1.31	+1.21 0 −1.21	+1.42 0 −1.42
4558.90	+0.92 0 −0.92	+0.94 0 −0.94		+1.19 0 −1.19	+1.29 0 −1.29
4351.97	+0.94 0 −0.94	+0.95 0 −0.95	+1.29 0 −1.29	+1.18 0 −1.18	+1.31 0 −1.32
4344.70	+0.89 0 −0.98	+0.92 0 −0.92	+1.20 0 −1.20	+1.11 0 −1.11	+1.25 0 −1.25

4344.7 is a fairly weak line; and the constituents are not easy to measure.

[1] *Proc. Camb. Phil. Soc.*, **14**, I, 41–84, 1906.

[2] Das Zeeman-Phaenomenon im sichtbaren Spektrum von Kupfer, Eisen, Gold, und Chromium. (Dissertation, Halle, 1907.)

[3] *Annalen der Physik* (4), **24**, 105–136, 1907.

It is difficult to explain the differences of the various investigators, although a probable cause may come from impurities, like iron, which would interfere with the energy of the field, both by absorption and by the attraction of small particles to the poles of the magnet. The experimental error from the strength of the field would be less in my observations than in the others; the field-strength I used was 39,980 C.G.S. units, and there can be no doubt of its accuracy; the maximum field-strength used by Miller was 32,300 units, that by Hartmann was 23,850 units and that used by Babcock was 23,400 units. The higher value of the field-strength is important in these close measurements; for, of course, the stronger the field, the more widely separated the constituents will be, with the consequent more exact measurements. Both Miller and myself used a Rowland large concave grating; Babcock, a plane grating; and Hartmann, an echelon instrument.

But whatever is the cause of the differences, it is desirable to place on record a comparison of the measurements of the separate constituents of the four lines on two different photographic plates taken at about the same time and under similar conditions, in order to indicate that the discrepancy does not come from very faulty measurements.

CHEMICAL LABORATORY
CAMBRIDGE, ENGLAND

MINOR CONTRIBUTIONS AND NOTES

WILLIAMINA PATON FLEMING

Williamina Paton Fleming was born in Dundee, Scotland, on May 15, 1857. Her parents were Robert and Mary (Walker) Stevens. Her education was obtained in the public schools of Dundee, where, at the age of fourteen, she was one of the pupil-teachers which were a part of the training used there at that time. After her marriage in early womanhood to James Orr Fleming, they came to this country and settled in Boston. In 1881, Mrs. Fleming, finding it necessary to support herself, entered Harvard College Observatory as a copyist and computer. It was on the eve of the development of a new and remarkable method of attacking astronomical problems; for celestial photography, which had been experimented with for several years, was about to be seriously undertaken at Harvard by the director of the observatory, Professor Edward C. Pickering. By placing a prism in front of the object-glass of the telescope, the spectra of all the brighter stars were obtained. Thus an almost untrodden field lay open for the investigator, a field that was destined to produce a vast amount of material for the astronomical discussions of the future. As the work progressed, Mrs. Fleming was put in charge of the original examination of the photographic plates, their care and storage, and the classification of objects found upon them. Gifted with great keenness of vision and a clear and logical mind, she at once gave evidence of ability for the work. Each photographic plate may be likened to the only existing copy of a valuable book, and, being very fragile, must be safely stored, and at the same time must be accessible, so as to be consulted readily at any moment. When a sufficient amount of material was at hand, the first general photographic classification of stellar spectra was undertaken, and was assigned to Mrs. Fleming. The results are published in the "Draper Catalogue," which forms Vols. XXVI and XXVII

Yours very truly,
W. P. Fleming
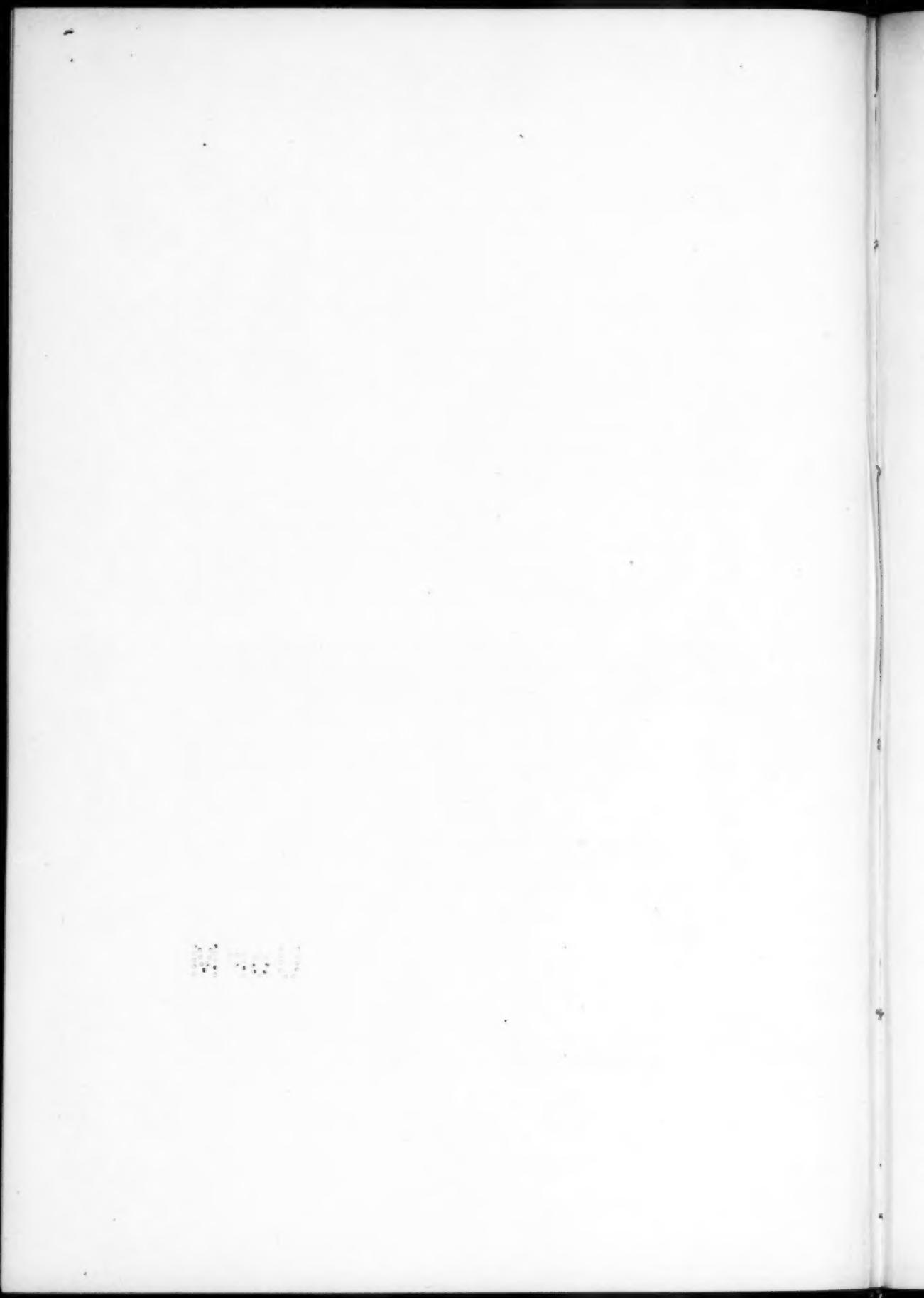
of the Harvard *Annals*, and gives the spectra of 10,351 stars, with measures of their photographic light. She observed, in classifying these spectra, that while a large proportion of them fall in classes resembling a few typical stars, there are also many that are peculiar. By the presence of bright lines in their spectra, she thus discovered ten Novae, and more than three hundred stars that vary in light. In the early days, when celestial photographs were rare, and some of these discoveries were attributed by skeptics to defects on the film, she never doubted the validity of the photographic evidence. Her industry was combined with great courage and independence.

She also found fifty-nine gaseous nebulae, ninety-one stars of the fifth type, Class O, and sixty-nine stars of the Orion type having bright hydrogen lines. She became interested in the red stars, whose spectra are of the fourth type, Class N, and appear very short on photographs taken with the objective-prism. Other spectra which resemble those of Class N, in the region between $H\beta$ and $H\gamma$, but which contain as much blue light as stars of the second type, she assigned to a new type called sixth type, or Class R. Just before her life-work was suddenly ended, she was engaged upon a portion of the *Annals*, called "Peculiar Spectra," which gives tables of all these objects with descriptions of their peculiarities. This is nearly all in print, and it is hoped it will soon be finished.

In a "Photographic Study of Variable Stars," Vol. XLVII of the *Annals*, Mrs. Fleming gave the results of her laborious work in measuring the position and magnitude of sequences for observing two hundred and twenty-two of the variable stars she discovered. Most of these variables were found by the presence of bright hydrogen lines, traversing a banded spectrum of Class M. This combination of lines and bands, which she called Md, was always an object of interest to her, and was considered as a certain evidence of the star's variability. She gave much attention to this class of spectrum, and divided it into eleven subclasses, depending upon the relative brightness of the hydrogen lines and the position of the maximum intensity of the continuous spectrum. A large part of her time was spent upon the preparation of the numerous

volumes of the Harvard *Annals* for the printer, and her power of grasping facts quickly and clearly was useful in final readings and corrections of copy and proof.

In 1899, Mrs. Fleming's work was recognized by the Harvard Corporation, and she was given an official position on the observatory staff, with the title of Curator of Astronomical Photographs. Successive honors followed. She was made an honorary member of the Royal Astronomical Society of London in 1906, and soon after, she was appointed honorary fellow in astronomy of Wellesley College. Only a few months before her death, the Astronomical Society of Mexico presented her with the Guadalupe Almendaro medal for her discovery of new stars. She was a member of the Astronomical and Astrophysical Society of America and of the Société astronomique de France.

Mrs. Fleming's health had been impaired for several years, but her great natural vitality and courageous spirit had sustained her through trying illnesses. Early in May she was evidently not so well as usual, and some days later, she went to a hospital for rest. Her condition was soon found to be critical, and pneumonia developed, which proved fatal on May 21, 1911. She left one son, Edward P. Fleming, who graduated as a mining engineer from the Massachusetts Institute of Technology in 1901, and is now chief metallurgist for a large copper company in Chile.

Mrs. Fleming was possessed of an extremely magnetic personality and an attractive countenance, enlivened by remarkably bright eyes. Although most of her life was spent in the routine of science, yet her human interests were numerous. Fond of people and excitement, there was no more enthusiastic spectator in the stadium for the football games, no more ardent champion of the Harvard eleven. Industrious by nature, she was seldom idle, and long years of observatory work never unfitted her for the domestic side of life. As much at home with the needle as with the magnifying eyepiece, she could make a dainty bag, exquisitely sewed, or dress a doll in complete Scotch Highland costume. She was never too tired to welcome her friends at her home or at the observatory, with that quality of human sympathy which is sometimes lacking among women engaged in scientific pursuits. Her

bright face, her attractive manner, and her cheery greeting with its charming Scotch accent, will long be remembered by even the most casual visitors to the Harvard College Observatory.

<div align="right">ANNIE J. CANNON</div>

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE, MASS.

CONCERNING THE ECHELETTE GRATING

In a paper in the May number of this *Journal* (**33**, 338, 1911), which has just come to my notice, Messrs. Anderson and Sparrow make two criticisms of a paper by R. W. Wood and myself which has appeared in the *Philosophical Magazine* (6), **20**, 886, 1910, and the *Physikalische Zeitschrift*, **11**, 1161, 1910. As it seems to me that Messrs. Anderson and Sparrow have misunderstood the intended scope of our investigation, I feel bound to reply to their criticisms.

The papers of Anderson and Sparrow and of Trowbridge and Wood both deal with the distribution of energy diffracted from a reflecting grating whose groove-form is supposed to be known, but the scope of the two investigations is very different. Whereas Messrs. Anderson and Sparrow calculate on diffraction principles (assuming certain simple conditions of reflection) the distribution of energy among the various orders, the work of Mr. Wood and myself was primarily experimental and consisted in the measurement of the distribution of the energy diffracted by a number of reflecting gratings of known groove-form.

In our analysis of our experimental results we at first attempted to secure a quantitative agreement with the theory of diffraction and developed equations for our experimental conditions which were similar to the equations published by Anderson and Sparrow.

We, of course, soon realized that in our unavoidable ignorance of the exact conditions under which reflection was taking place it was utterly out of the question to expect a quantitative agreement as regards energy distribution, but that the simple theory did predict whether or not a given order was strong or weak.

In preparing the paper for publication we preferred to present the matter of strong, weak, or absent spectra in a manner similar

to that in which the subject has already been treated by Schuster. It is to this treatment of the subject that Messrs. Anderson and Sparrow object, stating that "such reasoning ignores the process of diffraction altogether and is in our opinion not valid."

We ourselves drew attention to this circumstance in our paper, a fact which appears to have been overlooked by our critics.   Referring to our paper we find the objection raised by Messrs. Anderson and Sparrow expressed as follows:

> We shall in the present treatment discuss the results by the Fresnel method, considering the interference between secondary wavelets originating on the surface of the wave-fronts reflected from the oblique edges of the grooves. As Lord Rayleigh has pointed out, this method holds only when the width of the groove considerably exceeds the wave-length of light. In the present case, with our closest ruling, the groove-width was 1.5 times the wave-length of our longest waves, and it appears probable that in this case we are very near, if not beyond, the point at which we may safely employ the Fresnel treatment.

Further on we say:

> It is very questionable whether the upper wave-front 4, 3, 2, 1 will behave as a plane wave, i.e., travel out without diffraction; for each one of the elements of which it is composed has had to travel one or more wave-lengths before uniting with its neighbor.

The object of the investigation by Mr. Wood and myself was largely utilitarian in that we wished to determine the necessary conditions for obtaining intense grating spectra, and we have found that Schuster's treatment of the problem is qualitatively in accord with experiment; further that a treatment similar to that of Messrs. Anderson and Sparrow is also qualitatively but not quantitatively in accord.

The second criticism of Messrs. Anderson and Sparrow is that the energy distribution in grating spectra obtained by keeping the collimators fixed and by rotating the grating is not a "true" energy distribution.

We also drew attention to this in the following words:

> In order to make a thoroughly satisfactory study of the distribution of the energy it would be advisable to keep the angle of incidence fixed (for example, normal), and to swing the bolometer through the spectra. With the instrument at our disposal this was impossible, and it was necessary to make the spectra pass across the bolometer by rotating the grating. This complicates the

discussion of the results in no small degree, for the energy distribution varies with the angle of incidence, as can be seen with an ordinary grating.

However, there is this practical advantage to be gained in our method of observation: The angle between the collimators enters as a parameter in the expression for the retardation over a single element of the grating and so by varying this parameter the region in which concentration takes place may be varied, thus securing a wider range of wave-lengths in which the energy may be localized.

There is nothing in the paper by Messrs. Anderson and Sparrow to indicate that either of the difficulties which they raise had been foreseen by us.

A. TROWBRIDGE

PRINCETON UNIVERSITY
September 6, 1911

REVIEWS

Mathematical and Physical Papers of Lord Kelvin. Vol. V. Edited by SIR JOSEPH LARMOR. London: The Cambridge University Press, 1911. 8vo, pp. 602. 18s.

This collection contains five groups of the less important papers of Lord Kelvin and forms, not the last, but next to the last, volume in the series of his Mathematical and Physical Papers. For the student who is seeking a first-hand account of those great discoveries and principles which must always be associated with the name of Kelvin this volume will be of minor interest, for the reason that these epoch-making papers have already been reprinted in the preceding volumes; but for him who is interested mainly in the historical development of these principles the work under review possesses great value.

The first 134 pages, which have to do with thermodynamic problems, will be read mainly by the physical chemist and the physicist. As might be expected, this section covers a wide range in both time and topic, including a paper on "Stirling's Air-Engine," dated 1847, and another on the "Animal Thermostat," published fifty-six years later. This latter paper deals with an extremely difficult and attractive physiological problem, namely: How does an animal automatically keep its temperature down to blood-heat even when surrounded by a saturated atmosphere at a temperature higher than blood-heat?

Another paper, dated 1853, deals with the thermodynamic heating of buidings, and clearly anticipates methods which are only just now being employed to cool some of our best constructed houses.

Paper No. 119, although more than a quarter of a century old, apparently contains the fundamental idea involved in the theory of logging pipes recently worked out and experimentally verified by Professor A. W. Porter, of London. The at first astonishing theorem here proved is that a given amount of clothing will sometimes make a body warmer, sometimes cooler, depending upon the size of the body and the ratio of the thermal conductivity of the clothing to its emissivity.

The next 150 pages are devoted to papers on cosmical and geological physics, dealing largely with the secular cooling of the earth and with the sun's heat. Here is to be found Kelvin's presidential address before the Geological Society of Glasgow in which he shows a clear conception of the variation of latitude certainly as early as—and probably much

earlier than—1874, long before its actual discovery. As illustrating the author's scientific instinct and sense of caution we may cite the closing sentence of his B.A. address in 1861 on the "Possible Age of the Sun's Heat," a statement which clearly leaves room for the discovery of radium some forty years later: "As for the future, we may say with equal certainty that inhabitants of the earth cannot continue to enjoy the light and heat essential to their life for many million years longer, *unless new sources, now unknown to us*, are prepared in the great storehouse of Creation" (p. 144). That the subsequent discovery of very appreciable quantities of radium in the earth's crust has greatly diminished— not the scientific value—but the relative importance of these researches is now well recognized.

Homer Lane's problem—"the problem of convective equilibrium of temperature, pressure, and density in a wholly gaseous spherical fluid mass kept together by mutual gravitation of its parts" (p. 225)—comes in for elaborate discussion of great interest to all students of the solar surface.

The following 70 pages are given to "Molecular and Crystalline Theory," dealing mostly with problems of crystallography. Here may be found one of his best known papers "On the Size of Atoms."

A generation ago the following paragraph taken from this lecture was quoted in nearly every textbook of physics: "To form some conception of the degree of coarse-grainedness indicated by this conclusion, imagine a rain-drop or a globe of glass as large as a pea, to be magnified up to the size of the earth, each constituent molecule being magnified in the same proportion. The magnified structure would be coarser grained than a heap of small shot, but probably less coarse grained than a heap of cricket balls" (p. 296).

The remainder of the volume, some 250 pages, is occupied with electrical problems, largely concerning electrical measurements and questions of engineering. Many of these contributions antedate the divorce of electrical science and electrical engineering and are, for that very reason, full of interest.

It will be remembered that the verdict of the then Sir William Thomson and Professor Joseph Henry concerning the telephone, as exhibited at the Centennial Exposition in 1876, virtually established the success of that instrument. From the same point of view, the author's report on the Gramme machine, also exhibited in America for the first time at the Centennial Exposition, is worthy of notice, especially for its prophetic insight. The last paragraph runs as follows: "En outre

de ces relations théoriques tres-intéressantes, les machines Gramme ex-
posées ont des applications pratiques à l'électro-métallurgie, à l'éclairage
des manufactures, des phares et des navires, et serviront peut-être
aussi, dans l'avenir, à l'éclairage des villes et des maisons d'habita-
tion" (p. 413). In this section will be found the story of his series of
ampere-balances, the first satisfactory commercial and absolute instru-
ments for the measurement of electric currents; here also the history
of the Kelvin Bridge and the Electrostatic voltmeter.

That this eminent Scotch-Irishman possessed not only great flexi-
bility of mind but also that tenacity of opinion, characteristic of his race,
is evinced by his persistent defense of the direct current, as against the
alternating, for the transmission of power. The following remark
addressed to the Institute of Electrical Engineers in 1907, only a few
months before his death, will serve to illustrate both his generosity and
his persistence of view. "I am reminded," he says, "of a little prophetic
conversational statement made by Lord Rayleigh a good many years
ago. He rejoiced to see the use of alternating current coming in:
'Because,' he said, 'the whole world will now learn the subtleties of
electrical science, which they had no chance of learning before.' That
prophecy has been fulfilled. 'And,' he added, 'after that they will come
back to the continuous [direct] current.' I do not know that you will all
agree with that anticipation, but you will, I am sure, all enthusiastically
agree with Lord Rayleigh in rejoicing that we have had this twenty
years of alternating current, and of electrical science in its most interest-
ing characters, including in fact, wireless telegraphy, put before begin-
ners in electrical science as they now are in practical schools of electricity"
(p. 595).

Concerning the volume as a whole it will suffice to say that it is made
up in the faultless style of The Cambridge University Press, and that it
shows at many points the kindly and scholarly editorial supervision
of Sir Joseph Larmor.

                                                                        H. C.

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*A History of the Theories of Aether and Electricity from the Age of
    Descartes to the Close of the Nineteenth Century.* BY E. T.
    WHITTAKER, London and New York: Longmans, Green &
    Co. (Dublin University Press), 1910. Pp. xiv+475. $4.50.

This book, by the accomplished Royal Astronomer of Ireland, from
whose pen we have had already a work on analysis and one on dynamics,
in no way disappoints the expectations which these previous works

would naturally raise. The task of the historian of science is not easy. He must add to a thorough knowledge of the scientific side of the subject the qualities of historian and philosopher. For it is not enough merely to chronicle the steps of progress; it is necessary to see each advance or misstep in its true historical perspective, and to estimate its effect upon the science of the time as well as its bearing upon later developments. That the author has succeeded to a noteworthy degree in these respects will be conceded by all his readers.

The first three chapters deal successively with the beginnings of our knowledge of light, electrostatics and magnetism, and electric currents (galvanism). The progress is sketched in bold outlines—that of light from Descartes to Huygens, that of electrostatics and magnetism from Gilbert of Colchester down to the introduction of the potentials by Green, and that of currents from Galvani to Ohm, including the chemical theories of Davy and Berzelius and the classic experiments of Ampère. In each of these three lines, as yet independent, we follow the development of the theory up to a point where mathematical analysis begins to lay powerful hands upon it. The next two chapters deal with this mathematical development of the theory of the ether in the hands of Fresnel and his followers. These chapters make interesting reading. The subject is one which makes considerable demands upon the mathematical knowledge of the reader, and the author does not hesitate to make free use of the brevity and directness which equations offer in expounding these theories; but only those who have attempted to delve into some of the original memoirs of Cauchy, MacCullagh, and Kelvin will realize how signally the author has succeeded in presenting briefly the main points of these researches.

In the next chapter, devoted to the work of Faraday, we find electrostatics and galvanism united to form a single subject. It is to be regretted that the author does not give more than a small footnote to the work of Henry, whose discoveries, though not adequately recognized at the time, were by no means unimportant. After a chapter on the mathematical development of electromagnetism under the influence of the ideas of action at a distance, a return is made to the history of Faraday's ideas and of Maxwell's development of them. In Maxwell's theory we find at last the theories of light and electricity united on a common basis, and the known physical properties of the ether expressed in a single system of equations. The successes of this theory, as well as the shortcomings when applied to dielectrics, are well summarized. But the English physicists have not been content to rest on Maxwell's

equations—indeed we find that Kelvin, to the end of his long life, "never thoroughly believed it"—and in the succeeding chapter we have an account of the various attempts to construct mechanical models of the ether. It is a pity that the author did not see fit to include here some account of Osborne Reynolds' theory of a "granular ether," for it is surely worth at least passing mention. The followers of Maxwell, particularly Hertz, are discussed at some length. The last two chapters deal with the development of the modern theory of electrons, which finds its inception in the theories of electrolytic conduction of Faraday, as well as in the ideas of Faraday and Mossotti on the polarization of a dielectric. The treatment here is necessarily brief, but by no means inadequate, and the clearness of the presentation nowhere shows to better advantage.

It seems a pity that more attention was not paid to the physical theories of gravitation. It is true that none of these has been found adequate, and that the problem remains as yet detached from electromagnetic theory; but the subject would fall naturally into a history of the theories of the ether, and the author of the present work is so peculiarly fitted to discuss the question that the omission will be a source of regret to many.

That some slight errors or inaccuracies should creep into a book of this character is only to be expected, but the one or two we have observed are of too trivial a character to deserve mention, and affect in no way the general excellence of the work. The book is attractively printed, and remarkably free from misprints.

C. M. Sparrow

Johns Hopkins University